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NUCLEONICS

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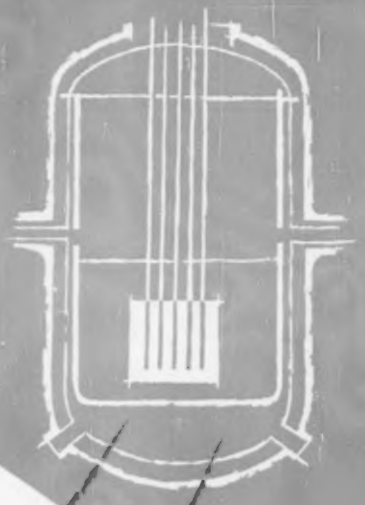
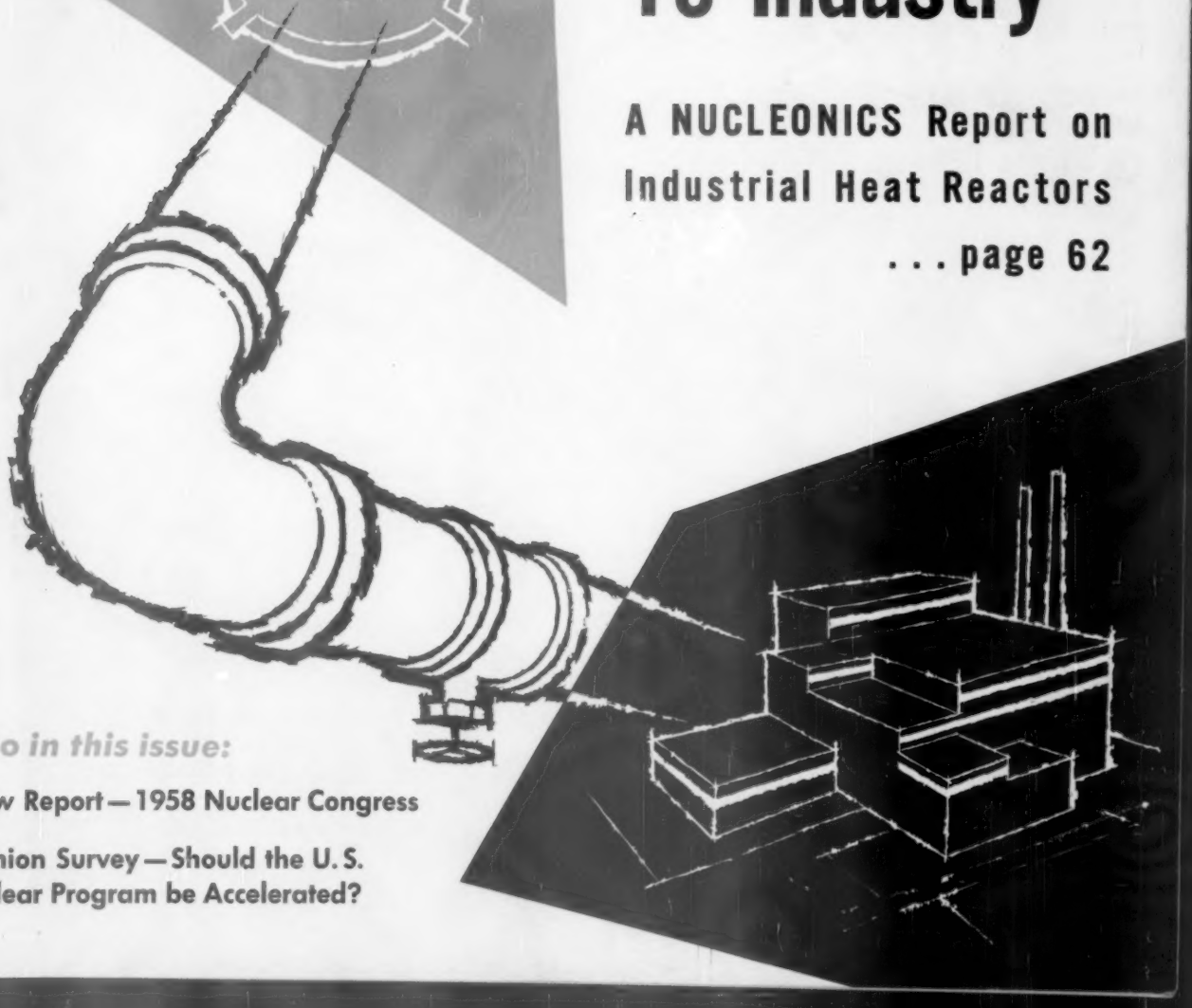


Piping Steam To Industry

A NUCLEONICS Report on Industrial Heat Reactors

. . . page 62



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Show Report—1958 Nuclear Congress

Opinion Survey—Should the U. S. Nuclear Program be Accelerated?

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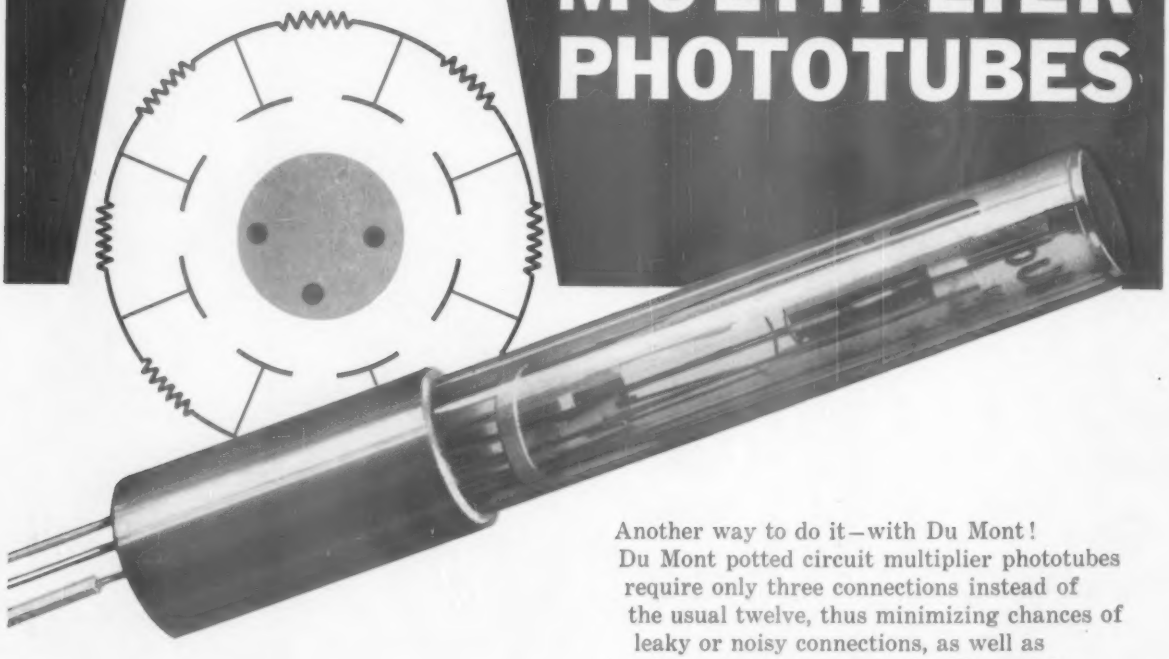

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VOLUME 16 NUMBER 2

FEBRUARY 1958

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About NUCLEONICS

The Fusion Bit

Getting the newly released information on controlled thermonuclear power into print (see page 90) meant having our normally hectic production schedules shift into even higher gear. In fact, for a while we felt like we were working on a daily newspaper.

What happened was this: we had known since December that there was to be a simultaneous release of fusion results by the UK and US teams "early in the new year" (NU, Jan. '58, p. 84). Feeling that any announcement of results in this all-too-secret field would be of vital interest to our readers we began to lay plans for carrying a report as soon after declassification as we could.

To cover the British end of developments we prepared to cable our able World News staff in London but those perspicacious news hounds recognized a hot story when they saw it and anticipated our request by cabling us "Planning fullest coverage from here of next Saturday's announcement of successful thermonuclear power experiments."

Then came the formal announcement that the results would be revealed on January 24 in the form of a series of scientific communications. The material was rushed to us by air express, just in time to be alloted six precious pages in the magazine. Overnight editing followed by mailing the copy to the printer resulted in its getting included in this issue, which you should be reading well within a month after the first announcement. While not all of our material can (or should) be put through on this time scale we are prepared to do it where it is pertinent.

The Scholarly Tradition

Several years ago we published (NU, Sept. '54, p. 20) an article based on a speech presented at the first Nuclear Congress by Alvin Weinberg, Director of Oak Ridge National Laboratory. In it he made a plea for "a scholarly tradition in nuclear technology." After discussing the characteristics by which a scholarly tradition in a field of technology can be recognized he pointed out the ways in which it was lacking in nuclear technology. Since that time (in part, because of efforts by Dr. Weinberg himself) much has been accomplished toward that goal—there is a professional society in the field and the universities have gained in importance as a source of fundamental inquiry in the field.

Nevertheless, a lot remains to be done, and as in all human affairs it must be done bit by bit. Which brings us to the point of the present discussion: There is included in our report on the 1958 Nuclear Congress an order form for preprints of papers in that meeting (page 78). The reason for having preprints is to enable those who attend the sessions to have prior acquaintance with the papers to be presented. Then less time need be consumed in mere presentation and more time can be devoted to meaningful discussion. In an age of parallel sessions and multitudinous personal distractions it is more difficult than ever for meetings to play their role in building a thoughtful ordered body of knowledge; this makes it even more important to use the time well and we hope you will follow our suggestion and equip yourself before hand.

Hot Air—or Steam

We have had the idea for this month's special report on industrial heat reactors (page 62) on a back burner for some time. When the AEC announed (Feb. '57, p. R6) that heat reactors were eligible for support under its third-round demonstration program we decided that it was time to bring our plans to a boil. In seeking material, we were quite surprised to find that there was very little attention being paid to the subject despite the general acknowledgement that prospects were as good (or as bad) for economic generation of thermal energy from reactors as for electrical power. This and other factors made for a long wait in assembling the present report.

We hope the report will serve to inspire further interest in the use of reactors for process heat and space heat. Certainly the present situation leaves a lot to be desired—a NUCLEONICS survey of major reactor designers and manufacturers revealed that except for a few companies the subject of heat reactors had been substantially ignored. This real opportunity would seem to call for a real effort particularly now that government support is available.

Bellos Vallecitos

If the industrial heat reactor report had not pre-empted our cover we would have devoted it to a very lovely picture of the Vallecitor boiling Water Reactor in its idyllic setting. As it is you must be contented with the fact-packed description in this month's reactor foldout facing page 76.

ABC ABP NUCLEONICS (with which are consolidated "Atomic Power" and "Atomic Engineering"), February, 1958, Vol. 16, No. 2. Published monthly by the McGraw-Hill Publishing Co., Inc., James H. McGraw (1860–1948), founder. Executive, Editorial, Circulating and Advertising Offices, McGraw-Hill Building, 330 W. 42nd Street, N. Y. 36, N. Y. Publication Office, 212 East York St., York, Pa. See panel below for directions regarding subscriptions or changes of address. Donald C. McGraw, President; Joseph A. Gerardi, Executive Vice President; L. Keith Goodrich, Vice President and Treasurer; John J. Cooke, Secretary; Nelson Bond, Executive Vice President, Publication Division; Ralph B. Smith, Vice President and Editorial Director; Joseph H. Allen, Vice President and Director of Advertising Sales; A. R. Venezian, Vice President and Circulation Coordinator. United States Subscription rate for individuals in the field of the publication $8 per year; Canada, other Western Hemisphere countries, and the Philippines, $10 for 1 year; all other countries, $15 for 1 year. Single copy prices: United States, United States possessions, and Canada, $1; elsewhere, $2. Position and company connection must be indicated on subscription orders. Second-class mail privileges authorized at York, Pa. Printed in U. S. A. Title registered in U. S. Patent Office. © Copyright 1958 McGraw-Hill Publishing Co., all rights reserved.

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Coming Features in NUCLEONICS

Next Month

Tritium Symposium

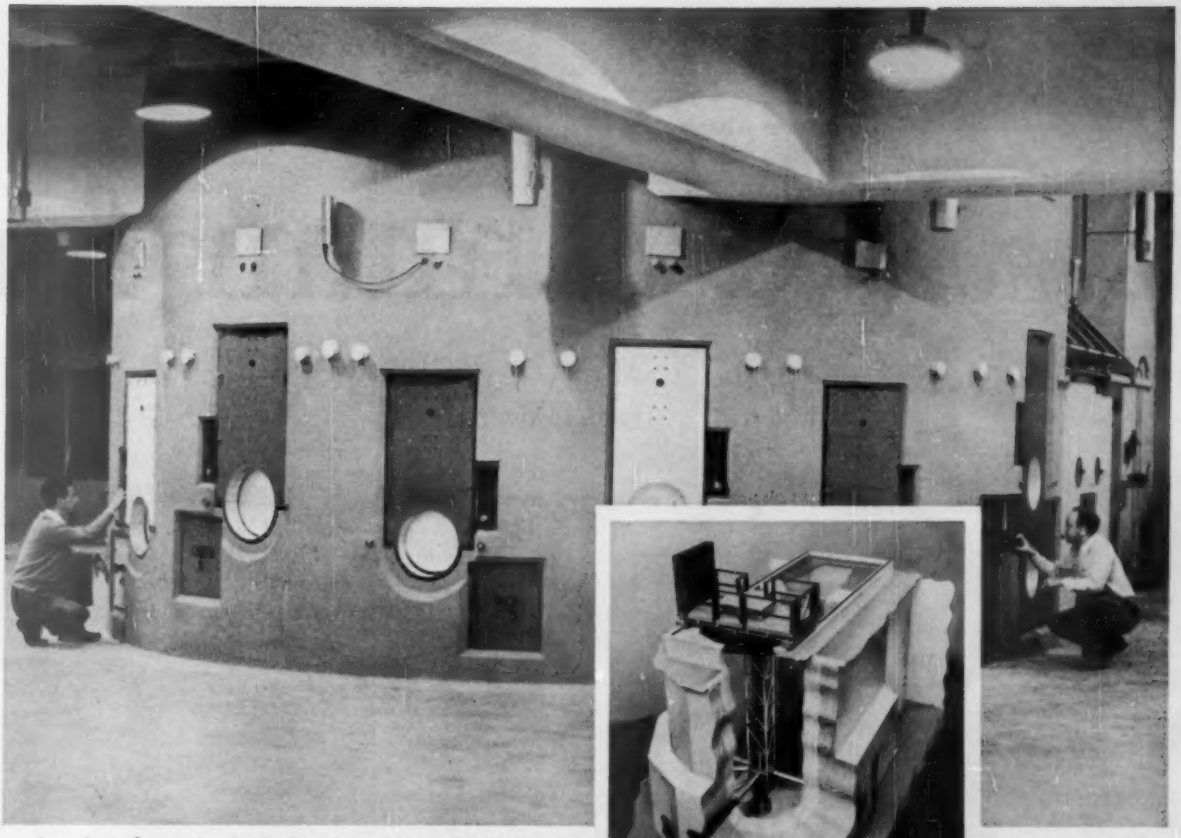
Reactor Foldout 5—Shippingport PWR

Fast Breeder Progress

Later Months

Radiation Effects in Polymers

Special Report on Reactor Control



A major advance in South American science is this recently activated research reactor at São Paulo University. Shown here is the working floor level of the 5-Mw unit.

Model of B&W Swimming Pool Reactor. Operative units are now supplying nuclear data at leading universities and research centers.

First South American reactor is dedicated at Brazil's University of São Paulo

Designed to produce 5000 kw of power . . . the highest capacity of any "swimming pool" type of reactor in existence . . . this new research reactor will play an important role in Brazil's contribution to the fields of medical, biological and industrial nuclear research. Operating successfully at the University of São Paulo, it has achieved Latin America's first sustained nuclear fission. The "swimming pool" reactor's name is derived from the water-filled concrete pool in which the core is submerged.

The reactor and the fuel elements which make up the reactor core were designed, fabricated and installed by The Babcock & Wilcox Company. The fissionable material in each fuel element is 20 percent enriched uranium 235.

Typical of B&W thoroughness and sound engineering were the extensive tests and research that assured successful operation. These included criticality experiments conducted in a similar research reactor in the U. S. under conditions duplicating those expected in Brazil. The result is an important step in President Eisenhower's "Atoms For Peace" program, which was designed to encourage and aid the development of nuclear energy for peacetime uses throughout the world.

In nuclear power development, B&W is a leading source for power reactors, propulsion reactors, research reactors, fuel elements, reactor components and experimental reactor development. The Babcock & Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, N. Y.

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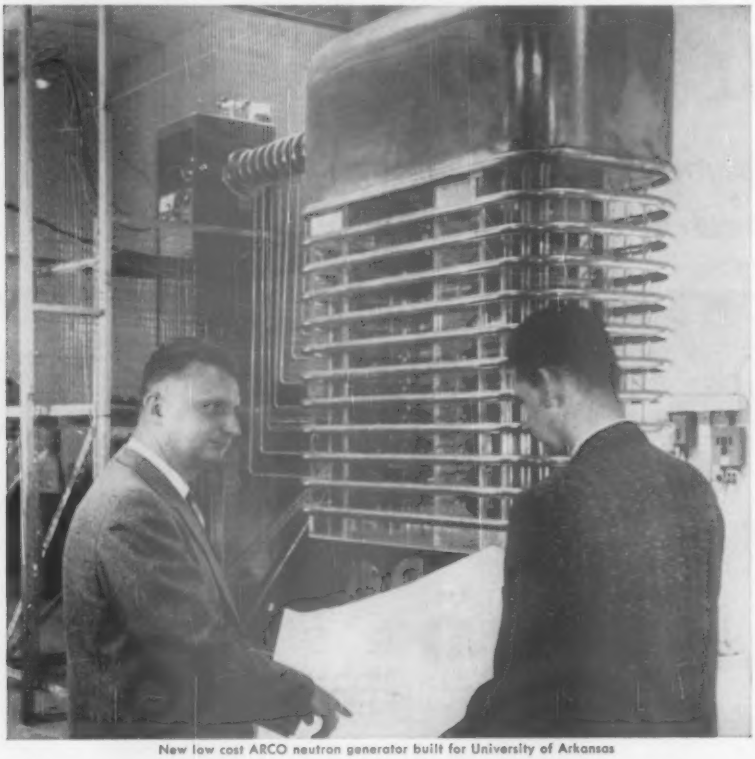

New low cost ARCO neutron generator built for University of Arkansas

10^{11} monoenergetic neutrons/second expected from new ARCO Cockcroft-Walton accelerator

The University of Arkansas expects output reaching 10^{11} monoenergetic neutrons per second from its new ARCO Model CW-D4 Cockcroft-Walton positive ion accelerator. Recently installed on the Fayetteville campus, the ARCO machine will accelerate a variety of ions for generation of monoenergetic neutrons of various energies, or for direct bombardment. The low cost accelerator was financed jointly by the University and the Atomic Energy Commission. Dr. Richard W. Fink of the University staff states that the purchase saved the University over 2 years effort had they built their own accelerator.

Research and Teaching

The versatile new machine equips the University for a broad program of physics and radiochemical research and instruction. Among the research programs planned are investigations of fast neutron cross-sections; decay schemes of short-lived nuclides; low-energy, heavy-ion nuclear reactions; and chemical states formed in nuclear reactions. By adding a subcritical assembly, the accelerator can be used as a safe device for reactor engineering instruction. Having few moving parts, the Model CW-D4 is extremely reliable. Its completely exposed power supply permits ease of service unattainable with pressurized equipment, and while accelerator dimensions are larger than those of more expensive pressurized apparatus, housing requirements are comparable.

High Neutron Yield— Precise Focus

The accelerator becomes an intense source of monoenergetic 14 Mev neutrons by utilizing the H^3 (d, n) He^4 reaction. The 400,000 electron volt Arkansas unit accelerates a 1200 microampere beam of deuterons to produce up to 10^{11} - 14 Mev neutrons per second. The machine can also accelerate protons, tritons and alphas for direct use or for production of copious yields of neutrons of lesser energy. Unusually precise focusing is attained. 1800 microamperes of 380 KV deuterons have been focused to a spot 1.2 mm in diameter.

Low Cost

Due to its simple, advanced design, the high-neutron-yield CW-D4 accelerator cost comparatively little. Funds for the ARCO accelerator were provided by the Atomic Energy Commission. The underground cell in which the accelerator is housed was built by the University.

Applied Radiation Corporation can build both atmospheric and pressurized positive ion accelerators for a wide range of energy and current requirements. Exact specifications can be met. Write for details.

Linear Electron Accelerator for Rent in Illinois

The Midwest Service Irradiation Center near Chicago (Rockford, Illinois) is now available for research and production use. Operating at from 2 to 10 Mev, the Center's Mark I Series linear electron accelerator treats both thin and thick materials. Unit density materials over one inch thick can be uniformly irradiated from one side with electrons, up to 4 inches with x-rays. By cross-firing, allowable thicknesses are more than doubled.

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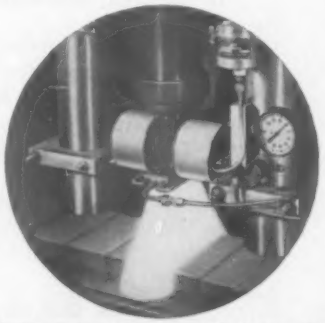
Write for detailed information.



Materials may be conveyed through the beam as shown or stationary experimental apparatus may be erected.

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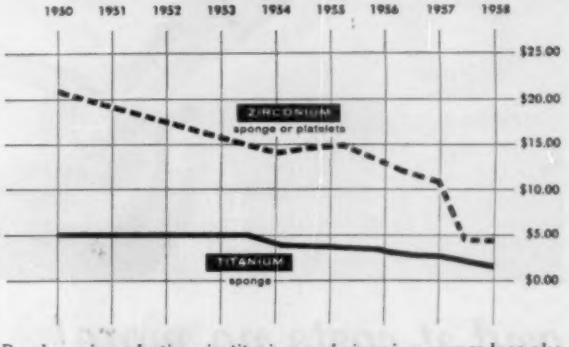

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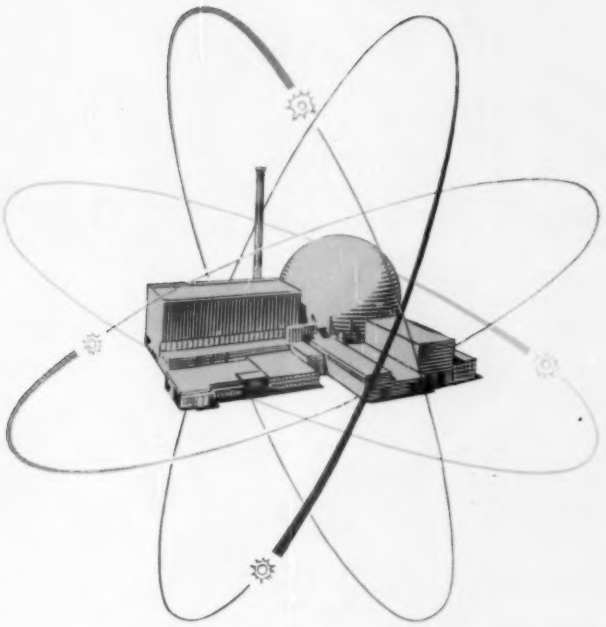

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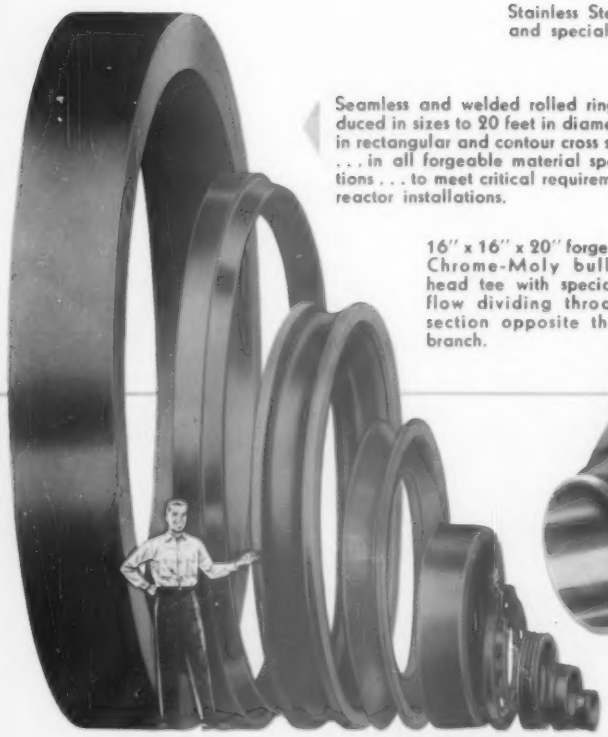

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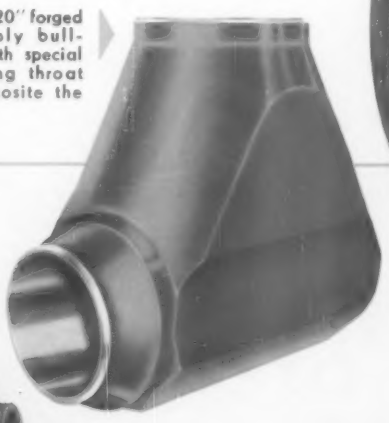

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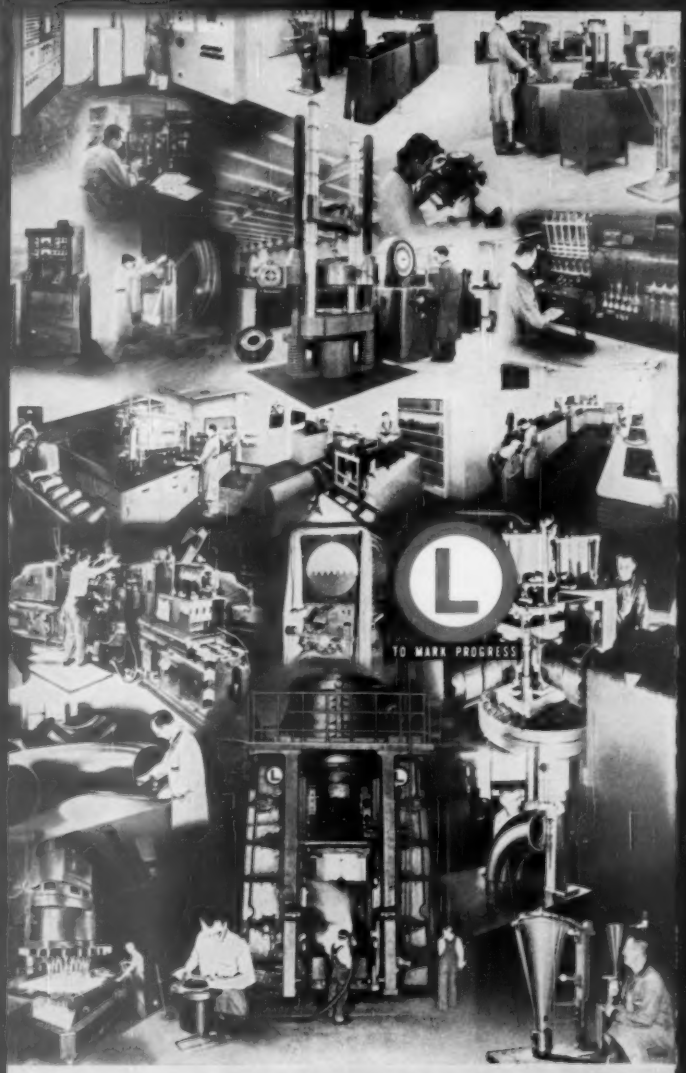

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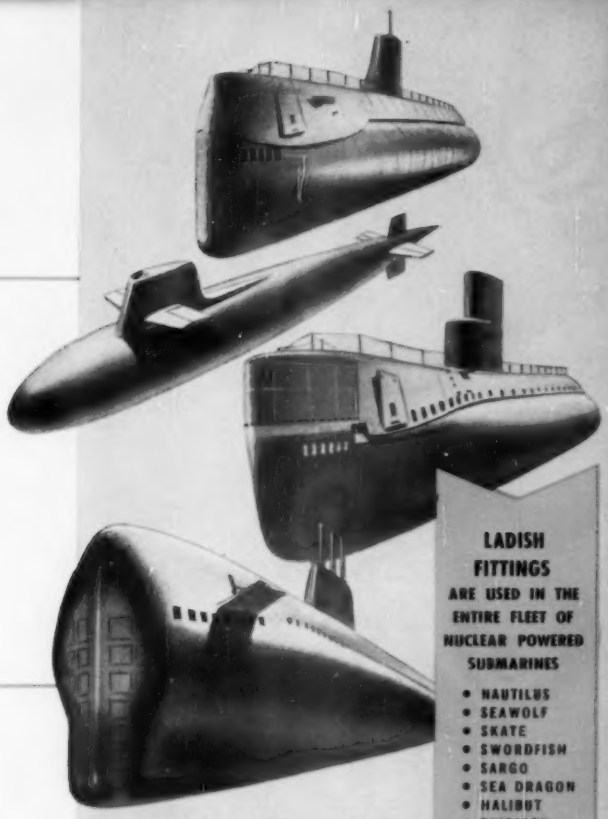

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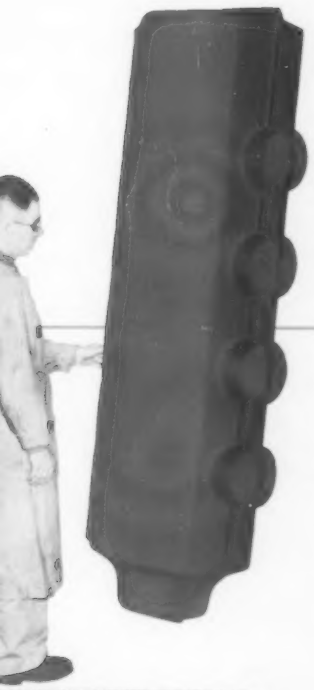

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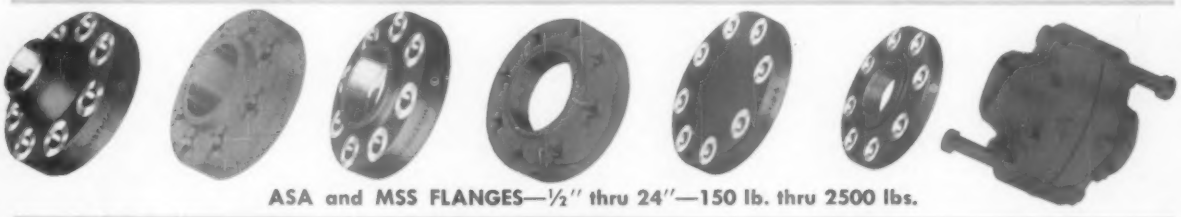

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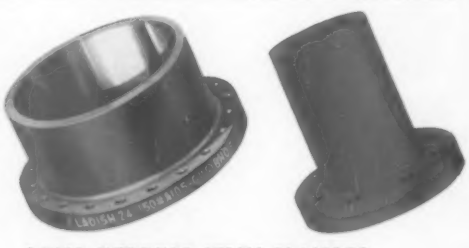

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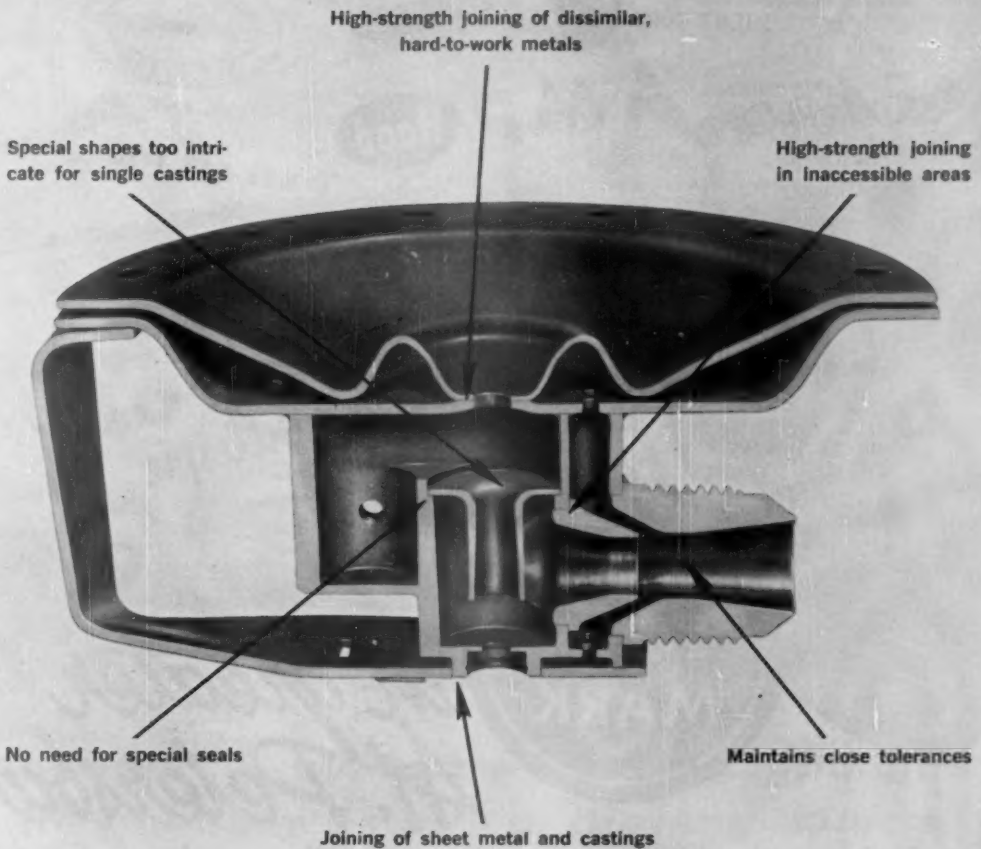
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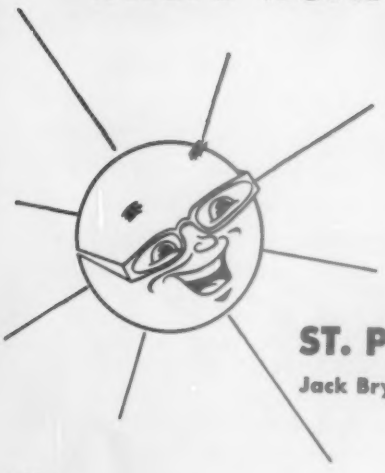

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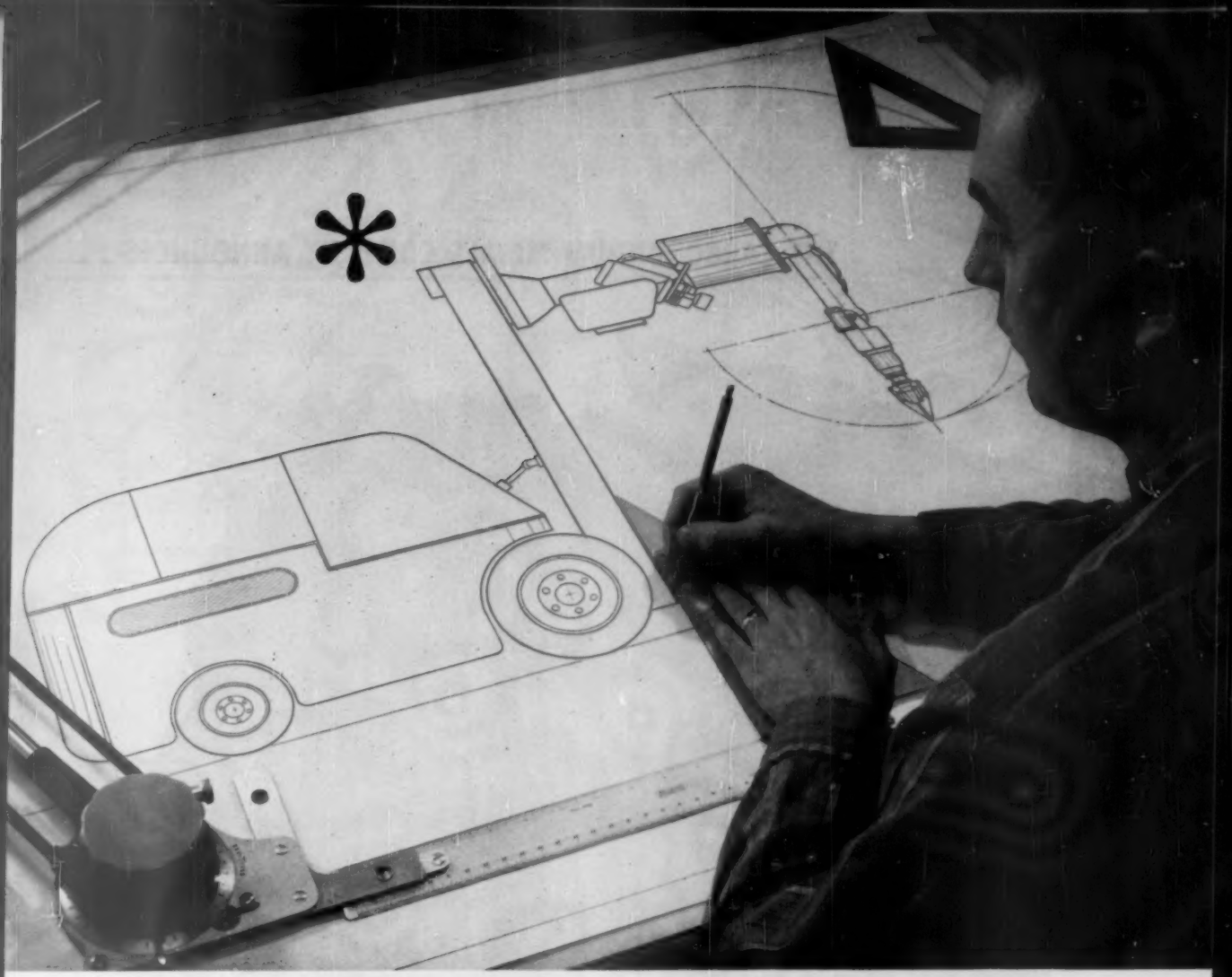

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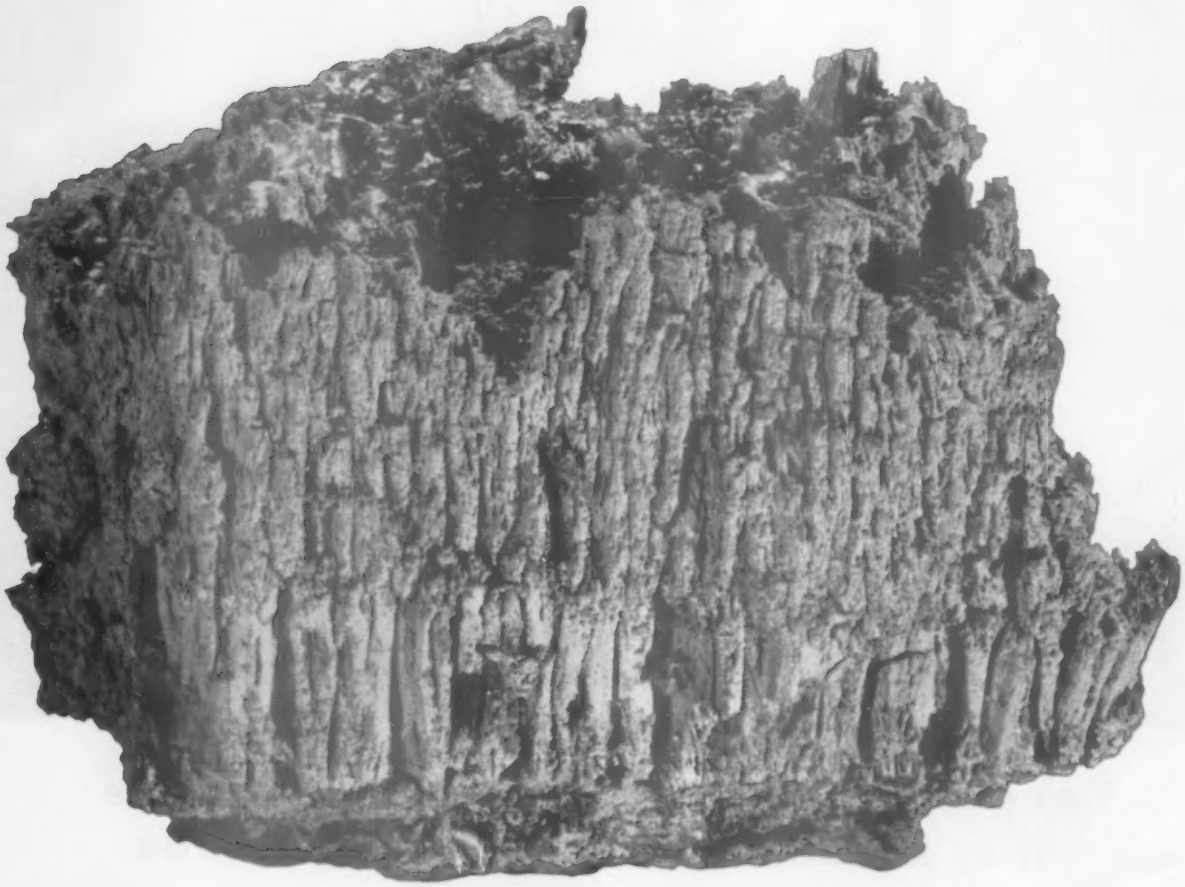

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ROUNDUP of Key Developments in Atomic Energy

Acceleration, Subsidy Backed by Atom Leaders in Survey

Statement of Objectives Held a Primary Need, NUCLEONICS Finds; Wide Acceptance Seen for Principle of Federal Financial Aid

• The nation's nuclear power program should be accelerated, and more money is indispensably required from AEC if this end is to be accomplished, a preponderant majority of key U. S. leaders in the major branches of the atomic industry believes.

• The first need is for a clear-cut definition of U. S. objectives in the field, which is felt to be lacking at present.

• The principle of a subsidy now receives wide acceptance in the private atomic industry—much wider than the word itself (which some consider a "dirty word," preferring to call it "assistance" or "financial participation"). Semantic questions apart, an overwhelming majority think AEC should help industry by greater support of research-development work; almost as many would like to see a subsidy on fuel costs, and a narrower majority favors subsidy of capital costs.

• The purpose of acceleration is to attain economic nuclear power as quickly as possible. Many leaders recognize that for reasons of U. S. foreign policy it has become desirable to achieve economic power from the atom as soon as possible even though abundance of fossil fuels does not yet make this vital in the U. S.

• As to the route to economic power: a decisive majority considers construction of full-scale reactors [50 Mw(e) or over] desirable; an even much greater majority favors construction of smaller reactors. Half the respondents favors construction of both pilot and full-scale plants.

• There is general agreement, even among utility men, that kilowatts alone are not enough.

• Abroad, the U. S. can look to solid markets for reactor equipment, components and materials for ten years or longer, according to most respondents; but the outlook for export of entire power reactors is less bright.

These are among the most important disclosures of a NUCLEONICS survey, just completed, of atomic industry leaders in the U. S. and eleven foreign countries. At home, the survey covered the views of atomic industry leaders among equipment manufacturers, privately- and publicly-owned electric utilities, architect-engineering firms, and reactor experts who advise the government on nuclear power technology. Abroad, in addition to manufacturers, utility executives and scientists, the survey also sought the opinions of the leaders of governmental atomic programs.

The latters' replies revealed that—although, as has frequently been said here, most countries plan to build their own power reactors as soon as they are able—they expect to be importing reactor parts for 2–20 years from other countries, and see the U. S. as a source of supply. In terms of money value, estimates of likely reactor-equipment imports ranged as high as $40-million by 1960, $200-million by 1963, $325-million by 1968. These high estimates were from Germany and Japan primarily; much more modest, yet not insignificant amounts were cited in Belgium, Italy, Sweden, Switzerland and elsewhere. (*Details of the foreign survey will be found starting on p. 20.*)

Back in '53

When the Joint Committee on Atomic Energy was holding hearings in the summer of 1953 on whether or not to revise the Atomic Energy Act of 1946, many of the same problems were already vexing the industry. Even then, 28 of 38 witnesses (NU, Sept. '53, 11) including the then-newly-named AEC chairman, Lewis L. Strauss, declared that the urgency of developing nuclear power was great. And on the question, who should be responsible for engineering and building civilian power reactors? five of 38 said it should be primarily the government; eight felt it should be primarily industry, and 15 favored joint government-industry responsibility. After 4½ years of accumulating experience and greater sophistication in nuclear power, a majority of industry leaders still feel that the program is not moving fast enough. But where barely one manufacturer raised his voice in favor of government development subsidy in 1953, that view has changed notably over the last five years as industry came to understand better the problems in achieving economic nuclear power.

Also in the intervening years, nuclear power has become, for better or worse, an instrument of foreign policy. So it was not surprising that in NUCLEONICS' survey there was a quite close correlation between the majority favoring acceleration of our nuclear power program and the majority that feels it is important for the U. S. to be the world leader in nuclear power. And even among the half-dozen who said "yes" to acceleration but "no" to the importance of world leadership, several said it was obvious Congress was determined to do all it could to assure U. S. leadership; that, therefore, however they might feel that this was not essential, they were proceeding with the question-

How Survey Was Made

Four questionnaires were drafted, two each for domestic and for foreign interviewees—one consisting of yes-no or short-answer questions, the other of two or three very broad and searching questions. The forms were sent to NUCLEONICS' correspondents in U. S. cities and eleven foreign countries, with instructions on whom to interview: a handpicked group of top atomic leaders—about 85 Americans and about 50 abroad. The results were collated by NUCLEONICS' editors in New York.

naire on the assumption that this effort would be made.

As with "subsidy," there were some demurrals over the word "acceleration" as implying ever-increasing speed, or as being too closely identified with the Gore bill; "expansion" or "broadening" were suggested.

Among seven suggested criteria of world leadership in nuclear power, the choices of the industry leaders emerged clear-cut: "availability of exportable technology" and "diversity of types of power reactors being studied or experimented with" received overwhelming approval as being important criteria, with "availability of exportable reactors" close behind. The other four all received a thumbs-down reaction, with "kilowatts of capacity planned" trailing furthest behind. Two other criteria suggested were "the most advanced technology," and "operating cost of reactors."

On Financial Support . . .

An interesting gulf developed in the replies to the questions on whether AEC should spend more money on power reactor development and on construction. An overwhelming majority favors AEC spending on development—and wants to see increased AEC support of work done by national laboratories and AEC's direct contractors—but a very much reduced majority wanted AEC money going for construction. Many stipulated

Results of NUCLEONICS Survey on U. S. Reactor Program

Note: First number represents "yes" answers, second number the "no" answers, throughout.	*Totals*	*Equipmt. Mfrs.*	*Utilities**			*Arch.-Engrs.*	*Reactor advisors†*
			Total	*Pvt.*	*Publ.*		
1. National policy objectives of the U. S. in atomic energy							
a. By whatever standards you use, do you think it's important for the U. S. to be the world leader in the field of nuclear power?	64-8	18-3	25-3	*18-3*	*7-0*	16-2	5-0
b. By whatever standards you use, do you think the U. S. nuclear power program should be accelerated?	58-14	19-2	18-10	*12-9*	*6-1*	17-1	4-1
c. Do you think the following are important as criteria of leadership:							
—number of power reactors in operation?	33-36	12-7	7-21	*3-18*	*4-3*	11-7	3-1
—number of power reactors under construction and/or contracted for?	28-38	10-8	5-22	*4-17*	*1-5*	11-7	2-1
—size of power reactors being planned?	28-37	9-10	10-16	*6-14*	*4-2*	7-10	2-1
—kilowatts of capacity planned?	17-49	8-11	7-20	*1-19*	*6-1*	2-15	0-3
—diversity of types of power reactors being studied or experimented with?	67-5	16-3	29-1	*23-0*	*6-1*	17-1	5-0
—availability of exportable reactors?	54-14	16-3	19-9	*15-7*	*4-2*	17-1	2-1
—availability of exportable technology?	65-3	18-1	18-0	*22-0*	*6-0*	17-1	2-1
2. Financial support of the field							
a. Do you think AEC needs to spend more money on power reactor development?	64-7	16-3	27-2	*20-2*	*7-0*	17-1	4-1
b. Do you think AEC needs to spend more money on power reactor construction?	40-29	15-4	13-17	*8-15*	*5-2*	9-7	3-1
c. If so, should AEC increase its support of work done by its national laboratories and its direct contractors?	42-16	11-8	17-3	*11-3*	*6-0*	11-5	3-0
d. Should AEC subsidize industry in the building of power reactors:							
—by increased support of research and development work?	62-8	15-4	27-2	*21-2*	*6-0*	16-1	4-1
—by subsidizing fuel costs?	57-12	15-3	22-1	*21-1*	*6-0*	12-6	3-2
—by subsidizing capital costs?	42-26	14-5	11-16	*6-15*	*5-1*	14-4	3-1
e. If there is a subsidy, who should get the subsidy:							
—the manufacturer?	26-33	6-11	8-12	*6-8*	*2-4*	9-9	3-1
—the customer (public or private utility or other in-industry)?	50-7	15-4	19-0	*14-0*	*5-0*	14-2	3-1
f. If there is to be a subsidy by AEC, who should determine how the money is to be spent:							
—AEC?	54-11	12-6	23-1	*17-1*	*6-0*	15-3	4-1
—the recipient of the subsidy?	33-21	10-7	10-9	*9-6*	*1-3*	10-4	3-1
g. In connection with the export of reactor equipment, should the U. S. government offer subsidies on power reactors?	34-30	10-9	13-11	*10-8*	*3-3*	9-7	2-3
h. If previous answer is "yes," who should be subsidized:							
—the U. S. firm?	23-6	7-2	8-1	*6-1*	*2-0*	7-2	1-1
—the foreign customer?	12-11	4-3	1-6	*1-5*	*0-1*	6-1	1-1
3. Acceleration of the reactor program‡							
If the U. S. power reactor program is to be accelerated, how should it be done:							
—by building large reactors (above 50,000 kw)?	39-21	11-4	15-9	*10-8*	*5-1*	9-8	4-0
—by building small reactors (below 50,000 kw)?	54-7	15-3	22-0	*17-0*	*5-0*	15-2	2-2

* Survey was sent to all private and public utilities with a record of interest in nuclear power; number of respondents in the two groups is to be compared with national installed capacity: 97-million kw for private, 12-million kw for non-Federal public.

† Not all answers received are tabulatable as this group of scientists frequently departed from questionnaire to answer in their own terms.

‡ Last parts of this question, not easily tabulatable, asked how many and what kinds of large and small reactors should be built; how many kw should be installed, if kilowatts were considered important; and what the time scale for acceleration should be. See main story for replies.

that they favored AEC construction spending in support of industry-controlled projects, but opposed any further AEC power plant construction. On this, as on a few other questions, the opposition of the privately-owned utilities made itself felt.

Of three possible places where a subsidy could be applied, all received favorable majorities, but again sharply differentiated: a preponderant majority welcomed the idea of AEC subsidizing industry in building power reactors by giving greater support to research-development work; a smaller majority favored subsidy of fuel costs. ("Yes, subsidize fuel costs, if it means fuel development," said a manufacturer. "Yes, under proper safeguards," said a public utility man. "Yes, for a period of time," a manufacturer. "Yes, reduce—not subsidize—fuel costs; subsidy as such should be avoided," a private utility leader. "No, present fuel costs are enough of a subsidy," a manufacturer. "No, this falsely influences plant design—rather subsidize operating costs in general," an architect-engineer. "No, it would tend to perpetuate uneconomic fuels," another architect-engineer. "Can't answer, because what is a realistic fuel cost?" a private utility man.)

A sharply-reduced majority came out in favor of the third alternative suggested, subsidy of capital costs. Here again the private utilities made their weight felt. Said one manufacturer: "No, if capitalists can't supply capital, it's tough."

About 40% of the respondents would have AEC give subsidy in all three areas. One at least would restrict subsidy to a separate program of development for export reactors. Several spoke approvingly of a formula —one that Lawrence R. Hafstad proposed in 1954 when he was AEC's director of reactor development— under which AEC would underwrite the difference in cost to a utility between a nuclear plant it might build and a conventional station of equivalent size that it would otherwise have to build.

Who Gets It?

Most of the leaders queried were willing to have the reactor customer get the subsidy, if there is to be one; far fewer favored giving the subsidy to the manufacturer. Said one manufacturer in the minority opposed to subsidizing through the utility: "He'll get his plant, but we won't necessarily get to economic power. Through the manufacturer you are more apt to attain your goal." There was a general feeling, on the other hand, that a subsidy paid to the utility would permit it to pay a viable price to the manufacturer for his hardware and that in this way the subsidy would reach both parties.

"He who pays the piper calls the tune" still applies, even in this realm, and on the question of who should determine how subsidy money is to be spent, "AEC" was the prevailing choice. "It's not the way to do it, but it's the way it will be done," was one hard-headed comment. However the number of stipulations urging "joint determination" ran high.

Whether the U. S. should offer subsidies on export of power reactors came out statistically almost even. Here there appeared to be a feeling that this was a foreign policy operation, coming under the foreign aid program, and that if subsidy were felt necessary, it should be handled by State Department. A program is offered by one manufacturer, who feels it would be "inappropriate" for the government to subsidize export of capital production equipment: "In all probability, the export market for power reactors could be opened up for American companies if the government would guarantee for a period of, say, 20 years: 1. price and availability of enriched uranium; 2. price and a market for recovered plutonium; 3. availability of capacity and guaranteed charges for reprocessing; 4. liberal financing arrangements."

In considering the time-scale for acceleration, "ten years" came out far in front—the same period of time that JCAE Chairman Durham is urging as the duration of a new reactor demonstration program (NU, Dec. '57, 18).

One veteran manufacturer proposes a ten-year program having as its goal construction of four large plants averaging 200 Mw(e) each per year for five years for a total of 20 reactors. Because of the long development, fabrication and construction cycle, completion of the program would take about 10 years. A capital subsidy of ~ $100/kw installed would, it's felt, give the private and public utilities adequate incentive to proceed with such a program, giving the U. S. 4-million kw installed nuclear capacity at a cost to the government of $400-million. "The chances are excellent," says the plan's author, "that such a program would result in attainment of economically competitive nuclear power by the end of the period if the program is concentrated in the area of very few reactor types" —those where the technology is best known and understood. For this reason emphasis is placed on the light-water-moderated reactor; however a few of other types such as liquid-metal-cooled or gas-cooled might be included. Likewise, the program should be concentated "on reactors of very large size because of their superior ability to reach competitive costs in a minimum time. Undoubtedly it will be desirable to authorize a few reactors of smaller sizes to meet special purpose requirements."

Another top manufacturer, who feels the national goal should first be defined in terms of a time scale and a program then worked out to implement it, suggests for it achievement of economic power in industrialized foreign countries in five years and in the U. S. in ten. Government should help industry, but not subsidize it entirely.

What Should Government Do?

A wealth of data was turned up by the survey's final questions, open questions on what ought be done in the nuclear power field in the next several years. Some of the salient suggestions as to what the government should do were these:

- More vigorous support of research and development, especially on fuel elements and reprocessing;
- Establish long-term national objectives [these two were mentioned most frequently, and then always first].
- Establish the level of government support for the next several years [the need for a program of almost any determinate number of years, and the great handicap in a long-range development field of working under the usual Congressional system of year-to-year appropriations, came out strongly].
- Establish long-term prices for nuclear materials under government monopoly.
- Enlarge the present program for testing safety characteristics.
- Assist industry on some formula that will give an incentive to keep cutting costs (*see box p. 20*).
- Establish fair contract procedures, and cease asking

for contributions from industry for the benefit of government projects [this from a bystander not involved in the Elk River miscarriage].

• Elimination or modification of such official or unofficial government concepts such as "give-away"; "closed-end commitments" by AEC, at least to the extent of protecting industry from "open-endedness" on joint projects; "full cost recovery" for AEC services to industry when both have common objectives; "assurance against abandonment" particularly when economic justification (in the sense of value of experience relative to its cost) for carrying a project to completion cannot be assured at outset. In this last connection, many pleaded for more flexibility in programming, to permit changing course as experience dictates.

• Abolish the 20% enrichment limitation on fuel exports, which implies that we don't trust our allies while at the same time it doubles costs for fuel fabricators because 20% alloy is so brittle the rejection rate is high.

• Improve AEC contract administration.

What Should Industry Do?

Most frequently mentioned were: perform more research-development, build more reactors, continue to develop promising reactor concepts, concentrate on getting costs down. Other points:

• Industry should bid on projects on a fixed-price basis, to gain incentive for cutting capital costs.

• It should adopt profitable pricing policy that will not involve substantial losses merely because of desire to break into the field. Pricing below cost is causing uncertainty and chaos among firms trying to develop stable markets.

• The equipment industry has been too quiet about the business problems it faces in establishing a sound basis for the future, should make the community more aware of its problems.

• Operate more realistically regarding costs and dates of completion.

• Steer clear of the public-vs-private power quarrel. This is stated by utility people as well as those in other groups.

Some Contradictions

Contradictions should be expected in any survey such as this, but a few gain significance because of the persuasiveness with which the conflicting opinions are set out, and the standing of the men behind them. Samples:

One reactor type *will* eventually prove to be *the* best, and we should concentrate on finding it.—It's likely that different reactors will have different applications for different purposes.

We should have a broad approach and not concentrate.—We should concentrate on the types now furthest developed, to hasten the arrival of competitive nuclear power, while continuing to develop more advanced types.

While most favored increased support for work done in national laboratories, one comment was that support of development work should "be fed through existing utility industry and major equipment manufactures"; if government goes on spending money on government labs for this purpose, "the experience and knowledge will reside in government organizations, not in commercial firms." Said another, "I think we'd get more for our money in this sort of development program than $300-million at the national labs. Where all information becomes general, you eliminate competition."

Subsidy Plan Suggested In Form of Tax Rebate

An intriguing plan for a subsidy to industry, with no cash handout and with built-in incentive, was offered in the NUCLEONICS survey by Lee Davenport, president of Sylvania-Corning Nuclear Corp. The plan: for the government to offer tax rebate and special depreciation allowances for accomplishment in nuclear plant construction.

Philosophically the plan is straightforward, Davenport says: taxes are the dues we pay to the government (representing the community) for the privilege of working in the U. S.; if the government wants certain people or companies to do something for the good of all, it makes sense to have the government offer to reduce dues in return for effort by the firms.

Incentive would be provided by pro-rating the tax rebate for accomplishment. The government-industry contract covering a joint project would specify $X worth of tax rebate if the plant were completed for $Y/kw installed capacity. If the plant were built for less, the tax rebate would be proportionately greater; if the company failed to meet its target cost, its reward would be less, likewise on a graduated scale.

Market Survey Abroad Brings Surprisingly Optimistic Results; Many See Imports from U. S. of Whole Reactors as well as Parts

A surprisingly optimistic forecast—optimistic from the point of American would-be reactor exporters, that is—was registered by respondents abroad in NUCLEONICS' survey.

That a nearly unanimous "yes" should be registered to the questions, "Do you expect your country to import equipment, components or materials for power reactors from other countries in the next several years?" and "Do you expect your country to import these from the U. S. in the next several years?"—this should be cause for satisfaction but not surprise, unless for its near-unanimity. But that, to the same pair of questions applied to "whole power reactors" instead of "equipment, components or materials," replies should be evenly split—this was quite unlooked for. That half the respondents—particularly considering their stature in their countries' nuclear programs—should expect a market to develop for entire U. S. reactors seems more optimistic than might have been foreseen. Having obtained its interviews on a strict basis of no-identification, NUCLEONICS must protect the anonymity of its survey respondents, and has to content itself with a flat assertion that they are top responsible officials.

Those who answered "yes" to any of the first four

questions were asked for how many years they judged they would be importing such things. This brought a range of five to twelve years and a median of about seven for whole reactors; a range of two years to "indefinitely" and a median of about twelve years for components and equipment. Predictions of long-term import positions came from Belgium, Germany, Switzerland, Italy, Sweden, Brazil and Japan. Declining to hazard predictions were respondents, in France, Netherlands, Australia and Mexico.

Lastly, the short-answer questionnaire asked overseas respondents what monetary magnitude, in round numbers, they expected their nuclear equipment imports to have in the next two, five, and ten years. Their estimates fell within these ranges:

Country	*Anticipated By 1960*	*Nuclear Equipment By 1963*	*Imports By 1968*
Australia	1–2	10–40	20 to >40
Belgium	up to 6	12–15	up to 60
Germany	15–40	50–200	100–200
Italy	1–15	50–150	100 to >150
Japan	22–30	30–190	60–325
Sweden	—	up to 1	up to 5
Switzerland	1–5	5–20	10–50

Obviously, these are guesses. But they are guesses by sophisticated people, in many lands, speaking with authority and with no incentive to give other than their undistorted opinions. If they are well-founded, they may portend a broader and more solidly-founded market for U. S. manufacturers than some have feared.

The French, as they see themselves, are in a special position. They feel they have a fairly sophisticated nuclear industry and that there is no reason why it could not handle France's needs. Three years ago France would have been interested in buying whole reactors, but since then she has developed her own technique and made her own fuel supply arrangements [plutonium] that led her in a direction away from that chosen by the U. S. Says an industrialist, "We don't wish now to drop all our work, which we think is valid, and adopt a system in which we have practically no experience, a system, moreover, that uses a fuel over price and supply of which we have little control. Furthermore we think your nuclear costs are perhaps higher than your estimates indicate, particularly on capital costs." Authorities involved in the Chinon reactor project, France's first civilian nuclear station, speak of power costs as low as 8–10 mills/kwh. A French CEA official sums up the reactor import situation as "Too little and too late."

Importing: Influences . . .

The free-answer questionnaire summed up the field in two questions: "What factors are influencing your country's decisions on matters related to importation of nuclear reactors and reactor equipment?" and "What obstacles if any are there to your country's importation of reactors and reactor equipment from the U. S.?"

The first question brought answers that were just about what might have been expected: cost of equipment and favorable financing terms; reliability; fuel availability and assurance of continued fuel supply; lack of domestic experience (Italy); imports a means of catching up with countries more advanced in atomic energy (Germany and Japan); earthquake-proof reactors (Japan); extent to which native industry can participate in construction power plant (Netherlands).

. . . and Obstacles

The question about obstacles to importing U. S. reactors and equipment, however, yielded some noteworthy comments.

Lack of U. S. sales effort was reported by several Australians independently. Said an Australian scientist: "British seem to be ahead of the Yanks in this field and they are doing more to keep us informed and interested." An Australian utility man: "We seem to hear more from England and they appear to be more interested in us as customers." An Australian industrialist: "Frankly, no Americans have ever called on us but the British have been trying to sell us on the advantages of their equipment." The dollar shortage was also mentioned by two Australians.

From Japan there is also a persistently-recurring theme: that the British have a working nuclear plant, the U. S. does not (so it is stated). "Lack of U. S. experience in producing power reactors, while the British have actually turned out a working model. It's believed cost of production with U. S. enriched-uranium reactors would be 10–20% higher than with the British Calder Hall. In any case, Calder-type costs can be calculated today, while U. S. reactor costs are still uncertain." "U. S. cannot yet show Japan a power reactor actually in operation." "As U. S. atomic power development has not yet reached the stage of commercial application, it is difficult to judge the economic and technical aspects of U. S. reactors. The diversification of reactor development in the U. S. has left an impression of confusion in Japan, especially in view of the fact that the British now have a working power reactor." It may be hoped that the entry into service last December of the AEC-Duquesne Light Co. PWR will mitigate this impression.

Other obstacles cited in Japan bear on enriched uranium—its higher cost, and dependence on a single source of supply for it. This point was made also in Brazil and elsewhere.

Said a German: "So far, obstacles and difficulties in cooperation with the U. S. have been of minor importance. However, after the events connected with the RWE project, we are expecting certain obstacles with delivery of enriched-uranium fuel elements." [The events alluded to are the collapse of negotiations between AEC and AMF Atomics for construction of the Elk River reactor, and AEC's alleged consequent refusal to license export of the identical RWE reactor without prior testing of the oxide fuel elements in the U. S. (NU, Nov. '57, 19). AEC officials in Washington told NUCLEONICS this was a "misconception" on the part of the Germans; that AEC has no licensing control over AMF's activities; that there is no licensing procedure for export of fuel, and that no reactor license was involved as substantial fabrication overseas was called for.]

The one single obstacle most often mentioned was—of course—high costs. Others: Insufficient information on costs of fuel, reprocessing and refabrication, and waste disposal (Germany); insufficient information on design (Italy); lack of guarantees on burnup, fuel supply, buy-back price, chemical reprocessing and inventory charges (Italy); high labor costs (Sweden); requirement for inspection of spent fuel elements and their return for reprocessing to the U. S. (Sweden) [no longer required—another misapprehension].

AEC Asks $250-Million Increase in Spending for '59; Reactor Budget Leveling Off, Up Only $16-Million

A $250-million increase in spending—most of it for military needs—was requested by the Atomic Energy Commission in its proposed budget for fiscal 1959, beginning July 1.

Although it was the smallest increase in years, President Eisenhower called it a reflection of "our determination both to increase the tempo of progress in achieving a greater nuclear military capability and to press ahead in our successful development of the peaceful applications of atomic energy."

The increase, from an estimated spending level of $2.3-billion this year to $2.55-billion next, will go mostly to step up procurement of raw materials and to expand production of weapons. The rest will go to jog, in varying degrees, the development of varied types of weapons, the development of both military and civilian power and propulsion reactors, research in biology and medicine, and isotope development.

Budget Levels Off

Particularly in reactor development, the 1959 budget represents a leveling off. Contrasted to the sharp year-to-year increases between fiscal 1955 and fiscal 1958, the boost for 1959 is relatively insignificant. In fiscal 1955, reactor development spending was $109-million; it rose $62-million in 1956 to $171-million; sailed $95-million in 1957 to $266-million; and jumped another $68-million in 1958 to an estimated $334-million. The 1959 boost is only $16.2-million to an estimated total of $351-million.

This increase of less than 5% from current spending amounts to holding the line on the reactor experiment program and anticipating some increase in support of the reactor demonstration program. Continuing emphasis will be given to basic research, and construction will continue on four multi-Bev accelerators.

Also, beginning this year and continuing into 1959, AEC intends to step up its research on reactor-fuels and waste-disposal systems.

In addition to its request for operating funds, AEC said it would make a supplemental request later this year to obligate $184-million for plant and equipment. Of this total $131.9-million covers projects to be started in 1959: $84.8-million for improvements and additions to raw material and weapons facilities; $20-million for the prototype destroyer reactor; $19.2-million for hot cells and other reactor supporting facilities (civilian and military); $4.2-million for research-development facilities; and $3.7-million for a variety of other projects.

Including facilities already underway, AEC's costs for plant and equipment in 1959 will run $226-million against the current program of about $250-million.

Reactor Budget Implications

As Table 2 shows, 1959 spending under the reactor demonstration program will be about $26.6-million, compared with an estimated $26.9-million this year. The Commission will directly support the 1959 activities of public and private power groups building reactors under the first, second and third rounds in this way:

- **First round.** Limited research and development assistance will be given to the Yankee, Fermi fast breeder and Nebraska Consumers projects.
- **Second round.** AEC will be participating in both research-development and construction on the Piqua, Elk River and Chugach projects and the currently-suspended Wolverine project.
- **Third round.** Limited research-development funds will be provided to Northern States. Also anticipated is an unspecified amount for research-development spending on several other contemplated projects—Carolinas-Virginia, Florida West Coast/East Central, and Pittsburgh Power & Light/Westinghouse.

Also shown in the reactor costs table is a boost from $90.8- to $97.7-million in AEC spending under its reactor experiment program. This item-by-item explanation of the 1959 figure was furnished by AEC's Reactor Development Division:

- **PWR at Shippingport.** Plant testing and operating data collection will continue; fabrication of the second seed for the core will be completed; design and development of the second core will be continued.
- **Boiling water concept.** EBWR, started up this fiscal year, will be directed toward investigation of the boiling heavy water cycle using both natural and forced circulation. ARBOR will continue under construction at Arco for completion about the summer of 1960.
- **Homogeneous concept.** Shakedown operations on Homogeneous Reactor Experiment-2 will continue in 1959. Additional work will be done at Los Alamos on the use of uranyl phosphate, rather than uranyl sulphate, as a fuel.
- **Fast breeder concept.** A little more emphasis in this field during 1959. EBR-2 construction beginning this year for test operation in fiscal 1960. Work will continue on LAMPRE, chiefly studies on designing transfer systems for molten plutonium. Spending will be up about $4-million from 1958, most of it for EBR-2.
- **LMF concept.** A start on fab-

1—Rate of Increase in AEC Budget Slows

Program	*1957 Actual*	*1958 Estimate*	*1959 Estimate*
Raw materials	$397,836,008	$596,901,000	$670,000,000
Special nuclear materials	581,602,626	578,600,000	592,000,000
Weapons	323,285,197	459,054,000	532,600,000
Reactor development	266,550,778	334,776,000	351,000,000
Physical research	59,344,215	71,471,000	71,500,000
Biology and medicine	31,519,984	37,895,000	43,000,000
Training, education, and information	7,815,945	16,850,000	18,500,000
Community	17,777,637	17,921,000	15,000,000
Program direction and administration	38,034,044	44,704,000	46,600,000
Security investigations	8,442,087	8,442,000	7,000,000
Other costs	6,619,603	8,137,000	6,687,000
Adjustment of prior year costs	−82,832		
Total program costs	1,738,745,292	2,174,751,000	2,353,887,000
Revenues applied (−)	−34,573,859	−34,875,000	−29,720,000
Net program costs	1,704,171,433	2,139,876,000	2,324,167,000

2—Reactor Program Costs Inch Up

Category	*1957 Actual*	*1958 Estimate*	*1959 Estimate*
Civilian power reactors	$54,291,286	$90,800,000	$97,700,000
Civilian power supporting effort	22,247,363	26,922,000	26,600,000
Commercial ship reactors	875,198	1,750,000	3,700,000
Army package power reactors	2,875,555	5,756,000	5,600,000
Naval propulsion reactors	71,662,530	86,844,000	87,000,000
Aircaft propulsion reactors	68,875,126	65,300,000	66,600,000
Controlled thermonuclear project	10,734,745	23,550,000	25,500,000
All other	34,988,975	33,854,000	38,300,000
Total reactor development	266,550,778	334,776,000	351,000,000

rication of the Liquid Metal Fueled Reactor Experiment is not expected until 1960 (earlier, the hope had been 1959). Research-development effort will continue in 1959.

• **Organic Moderated Reactor.** The OMRE at the Idaho reactor testing station will continue to be operated, testing several organics for suitability as moderators and coolants.

• **Plutonium recycle program.** Under construction at Hanford will be a Pu fabrication lab and a Pu recycle test reactor (NU, Jan. '58, p. 62) for testing various fuel elements. The reactor design is near readiness and construction will begin this year for completion in fiscal 1960.

• **Pressurized heavy water concept.** About $4-million will be spent at Savannah River to continue reactor-evaluation design studies and analysis of experimental work; research-development in its early stages looking toward a completed design; no construction anticipated in foreseeable future.

• **Gas-cooled concept.** Design work is to be completed this year, and a report will be made to the Joint Committee this spring. No money is asked by AEC beyond the $3-million appropriated last year; it's up to JCAE to work out the schedule for fiscal 1959.

• **Other concepts.** AEC makes a "continuing evaluation" of new concepts. About $1-million is being spent this year on new concept studies; some $1.5-million in 1959 budget.

Satellite-Age Congress Faces Crucial Year on Atom; '202' Hearings Feb. 19 Follow 2-Week Research Inquiry

Out of a whirl of demands, statements and charges marking the convening of the first satellite-age Congress has emerged the indication—if not concrete assurance—that something will be done this year to accelerate nuclear development in power, propulsion and research.

The political fight over immediate acceleration of power reactor development is still very much alive. But there is a new area of agreement on a program to succeed the five-year reactor demonstration program and a new feeling for extending federally-centered research effort on the atom.

Among the developments in January highlighting research anxiety were:

• Rep. Price's JCAE subcommittee on research and development scheduled hearings preceding the annual "202" state-of-the-atom hearings to underscore the extent of current basic research activities. The research hearings began Feb. 3 and run through Feb. 14; the statutory hearings pick up almost immediately—on Feb. 19—with AEC officials, then industry witnesses.

Major areas being explored by the Price subcommitee and some 50 top scientists are chemistry, metallurgy and nuclear physics, with stress on high-energy accelerators and controlled fusion.

• The National Science Foundation drew special attention to a recommendation of its advisory panel on high-energy physics for an increase of $20–50-million in the $40-million annual spending rate for construction and operation of high-energy accelerators. Also recommended was an increase in support spending by NSF, AEC and the Defense Dept., including development of new accelerator types.

On the near- and far-term needs for increased federal spending on reactor development, there were these developments:

• JCAE and AEC have completed the preliminaries on a program to succeed the five-year plan. AEC, carrying the ball in the early going, is beginning to "see the shape" of a proposal extending federal participation into the late 1960's. The AEC plan presumably would be presented to JCAE later this session for bilateral consideration. AEC Chairman Strauss described the situation this way:

"We have under active consideration within the Commission and will later have in consultation with the Joint Committee a review, a reappraisal, of the power situation in the light of the more plentiful supply of nuclear material, and the advancements that have been made in the art in the last year."

• To boost the attractiveness to foreign buyers of U. S.-designed reactors, AEC is considering "an intensive program for the development of improved fuel elements" for water reactors. Commissioner Vance dropped a loud hint that several more reactor contracts might be let in Western Europe this year.

• Sen. Albert Gore (D.-Tenn.) offered "my 1958 version" of a bill to require Federal construction of prototype reactors. Going well beyond earlier versions, this one authorizes expenditure of $1-billion, $400-million of it for reactor construction, the rest for development of nuclear-powered space vehicles and an accelerated research effort on fusion.

"We simply cannot afford the complacency and the unhurried manner which has marked our program to date," Senator Gore told the Senate.

• Chairman Strauss and fellow-Commissioner Willard Libby made strong claims for the U. S. position to date. In a year-end review, Strauss put the number of commercial power reactors building or planned at 23, with installed capacity of 1,300 Mw(e) by the mid-1960's. In a speech at Eugene, Ore., Libby said U. S. know-how and supply abilities on natural uranium, heavy water and enriched uranium place us in "an absolutely commanding position in the atomic power development of the future." He added:

"We supply the cheapest atomic fuel, we supply the cheapest heavy water, and we are one of the world's principal producers of natural uranium. It is not too much to say that whatever the future development and in whatever direc-

tion atomic power moves, our position will be an absolutely commanding one from the point of view of raw materials alone."

Shortly before introduction of the Gore bill, JCAE created a Special Subcommittee on Outer Space Propulsion, headed by Sen. Clinton Anderson (D.-N. M.). He and other Democrats called for a speed-up of Project Rover—development of nuclear-propelled space vehicles—to hasten conquest of space by the U. S.

Two other Democrats, however, threatened JCAE's very existence with a proposal to demolish the joint group in favor of permanent House and Senate committees on science. The bill, sponsored by Senators Hubert Humphrey (D.-Minn.) and John McClellan (D.-Ark.), was not given much chance this year.

Senator Gore added to JCAE's already-full schedule with an inquiry into AEC's uranium ore procurement policies. Hearing dates will be set after AEC submits the results of a survey—due by March 15—of the domestic industry's "hardships and problems." Pending the JCAE study, AEC has halted foreign ore procurement.

In the meantime, Rep. Chet Holifield (D.-Cal.) and Sen. Henry Jackson (D.-Wash.) demanded (1) a sharply-increased building program of nuclear subs and (2) a concerted effort to develop an "underwater satellite"—a roving, missile-launching platform. The Navy indicated it would seek funds to add up to six nuclear subs to the 22 programmed (*see p. 28*).

Finally, Rep. Craig Hosmer (R.-Cal.) won the JCAE seat vacated by Sterling Cole. He backs AEC's partnership-with-industry policy.

Uniformity in Regulations Sought in Forum Meeting

Promotion of uniform regulation of nuclear energy on the federal, state and local level was begun by 40 government and association spokesmen meeting under the auspices of the Atomic Industrial Forum. The long-range effort is aimed at maximizing uniformity of health and safety rules, and promoting the atom at the community level. In the wind as a result of the one-day meeting are: 1. possible creation of a Forum committee on state and local activities; 2. a bigger meeting bringing together officials at all levels of government.

Two More Reactor Projects Underway:

1-General Dynamics: Ship

MGCR, the Maritime Gas-Cooled Reactor, has been assigned to General Dynamics Corp. by AEC and the Maritime Administration. The selection is contingent on negotiation of a contract which will cover development of a prototype gas-cooled reactor, closed-cycle gas-turbine plant for merchant ship propulsion. Five to seven years are estimated to be required from initial contract award to complete construction of the plant.

GD won the much-sought-after award from 18 bidders (NU, Nov. '57, 21). The project will be a joint undertaking of two Dynamics divisions: General Atomic in San Diego, where basic research, reactor design and construction are carried out, and Electric Boat, whose Groton, Conn., shipyards built *Nautilus*, *Seawolf*, *Skate*, and are building four more nuclear submarines. Initial phase of the project will include development of high-temperature fuel elements, reactor controls, and selection of coolants, moderator, and compatible turbine machinery. Thereafter "design, fabrication, erection and test operation" of a prototype will follow.

The closed-cycle gas-cooled nuclear shipboard engine is the second stage of a joint AEC–MA program to achieve an economic nuclear merchant ship (NU, Nov. '57, 78); the first stage is the 21,000-ton passenger-cargo ship N. S. *Savannah*.

Zirconium vs Steel Costs To be Discussed in N. Y.

Two symposia on the economics of zirconium vs. stainless steel, used as both cladding material and structural material, will be held in New York within the next month. Sponsored by Columbia-National Corp., a principle zirconium producer, they will be based on the results of a year-long, $25,000 research project carried out for Columbia-National by Manson Benedict of MIT. Correlation of fuel enrichment and material costs and the break-even points with Zr and stainless were studied in the cases of five specific reactors: SRE, Vallecitos, Yankee, the propulsion reactor for *Savannah*, and Canada's first power reactor. The first symposium will be held Feb. 13 for reactor designers (by invitation), and the second early in March for producers, melters and converters of Zr sponge.

2-NDA: East Central Group

Nuclear Development Corp. of America has a study contract with the East Central Nuclear Group covering a high-performance heavy-water steam-cooled reactor, NUCLEONICS has learned; the project is separate and distinct from the heavy-water gas-cooled pressure-tube reactor on which ECNG is collaborating with the Florida West Coast group (NU, Jan. '58, 17).

The 14-utility ECNG group, spearheaded by American Gas & Electric Corp., is to get a preliminary report in a matter of six months; NDA has already been working on the project for a like period. Involved is a heavy-water moderated, natural uranium fueled reactor; low-grade steam is made outside it by mixing steam from the reactor outlet with condensate from the turbine, and this is then fed into the reactor to produce superheated steam.

Four Firms to Study Small Military Reactors

Curtiss-Wright Corp., General Electric, and a team of Nuclear Development Corp. of America with General Motors will get AEC contracts for nine-month studies on small reactor systems for military use. Extreme compactness, low operating weight, and moderate power output [up to 2 Mw(e) net] are the criteria, and the studies are to determine which reactor concepts show most promise in this direction. Twenty-eight firms bid to make the studies, in response to an AEC invitation last October.

Britain Reported Asking U. S. Enriched Uranium

Britain has requested the U. S. to supply her a substantial amount of slightly-enriched uranium, AEC officials were quoted as having disclosed last month. The request is reported to have been made about a year ago. This confirms a NUCLEONICS report even longer ago (NU, May '56, 23) stating that negotiations were underway for a separate agreement between the two countries. Britain has one gaseous enrichment plant at Capenhurst near Liverpool, but its output is very Limited. Although regarded as the champion of natural-uranium, Britain has said her civilian A-stations would use slightly-enriched uranium.

World News

Italian Contract for Westinghouse

SELNI (Societa Elettronucleare Italiana), a group 55% owned by Edisonvolta of Milan, has finally agreed on terms and signed a contract with Westinghouse for a 134-Mw(e) Yankee-type A-plant to be installed on Edisonvolta's grid (NU, Jan. '57, R1). SELNI has applied for a $24-million loan from the Export-Import Bank of Washington to finance materials and machinery purchase, and to issue bonds to increase its capital by $10-million.

Japan to Buy a U. S. PWR, Building Unit

Japan's AEC has approved plans of the Atomic Energy Research Institute to buy an 11-Mw(e) pressurized water reactor in the U. S. in the 1958–59 fiscal year, for operation by mid-1961. JAEC's new long-range program calls for installation of 600 Mw(e) nuclear capacity by 1965, 7,000 Mw by 1975. Also, first blueprints of Japan's first domestically-built reactor have been completed: the natural-uranium, heavy-water research and isotope-production reactor with 10 Mw output will be completed at the Research Institute in 1960. Design is similar to Canada's NRX-reactor. Hitachi Ltd. will build the reactor itself; Mitsubishi group firms will provide water and gas facilities; Tokyo Shibaura Electric and Fuji Electric the instrumentation and controls, and Ishikawajima Heavy Industries the isotope-handling equipment. JAERI and industry representatives are now in Canada to obtain data; first orders are to be placed in March, work on the building to house the unit will start in April, and assembly of the reactor itself at year's end.

NPD Design Changes Completed

An oxide fuel element has been developed in Canada for use in horizontal pressure tubes carrying fuel and heavy-water coolant, and a new conceptual design for a core on this system has been evolved. Pressure tubes, which would surround individual fuel elements and coolant fluid, would have a great advantage over the huge, bulky, difficult-to-fabricate and expensive pressure vessels that now contain whole cores of water reactors, by reason of their smaller size and weight and easier replaceability; until now two difficulties had been to fashion piping that would take pressures of 2,000 psi and to make reliable pipe-to-header welded seals. Consequently the plans for the Nuclear Power Demonstration reactor, Canada's first power unit, have been changed over to this new design (NU, June '57, 26); alterations are completed and construction "is expected to proceed by mid-summer this year." Canadian General Electric is building the 20-Mw(e) plant for Atomic Energy of Canada Ltd. and Ontario Hydro. The new design can be used in large-scale plants of "several hundred Mw(e)"; one such is already under study at Chalk River by Candian utility engineers. Another study has been made by Canadian Westinghouse (*see p. 26*).

Swiss Girding for A-Push

The Swiss government has granted a special subsidy of $5.1-million for nuclear research and training to the Swiss Fund for Scientific Research, plus $1.1-million to Réacteur S.A., the nonprofit combine set up by the main Swiss industrial firms working in the field (NU, June '56, 19B). A $4.66-million laboratory (with cyclotron and accelerator) is projected for Switzerland's famed Polytechnic Institute in Zürich. Four tons of heavy water to be produced in Switzerland have been sold to France, and a Swiss-Canadian agreement for cooperation, including provision for delivery of Canadian uranium to Switzerland, is being negotiated. Energie Nucléaire S.A. of Lausanne, which will build the country's first power reactor, has released sketches of the 5-Mw(e), 25-Mw(th) boiling reactor with intermediate heat exchanger to be built in a hillside for 1964 operation.

Euratom Names Leaders; Huet Heads OEEC Unit

Louis Armand, head of the French National Railways, who in a few short years turned a war-devastated system into the world's best, was named chairman of the five-man Euratom Commission. He had been one of Euratom's "three wise men." Joining him on the Commission are vice-chairman Enrico Medi of Italy, Rome Univ. physics professor; Paul de Groote of Belgium, president of Brussels Univ. and administrator of CEAN, the Study Center for Applications of Nuclear Energy; Heinz Krekeler, present German ambassador to Washington and a former chemist at I. G. Farben; and Emmanuel Sassen, Dutch lawyer, member of parliament and head of Holland's Christian Democratic Party. Commissioners will serve six years. Final decision on location of Euratom's permanent headquarters has been postponed. First task of the Commission, Armand says, will be to establish a precise calendar to enable Euratom to meet its 15-million kw target. Another Frenchman, lawyer Pierre Huet, was named director of the new European Nuclear Energy Agency founded in December by OEEC (NU, Jan. '58, 22).

"Thermocouple Reactor" in Germany

Siemens-Schuckert of Erlangen got a preliminary patent (DAS 1,021,962) on a nuclear reactor transferring heat into electricity by theromocouples. Several variants are proposed.

Frankfurt's Reactor Critical

Germany's second reactor, the Atomics International-built solution-type research unit at the Univ. of Frankfurt, began operating Jan. 10; it had been scheduled to go critical early in November (NU, Nov. '57, 89). A similar AI unit now being assembled in West Berlin is now scheduled to start operating in April.

Anglo-Italian Bilateral Signed

Italian Foreign Minister Pella and British Ambassador to Rome Sir Ashley Clarke last month signed an agreement for atomic cooperation under which Britain will supply the natural uranium—amount unspecified—for the reactors she will furnish to Italy. The agreement is described as also binding even if another country should furnish natural-uranium-fueled reactors, provided Britain had examined and approved the project. Italy's first bilateral, signed last July 3 with the U. S., covers supply of enriched uranium.

Poles Plan A-Ship

Poland will launch its first nuclear-propelled ship in 1970, *Trybuna Ludu* of Warsaw says; a working group has already been set up in the Polish Academy of Science to draft blueprints for a 35,000-ton, 20-knot tanker, powered by an organic moderated reactor driving a 24,000 hp engine (NU, April '57, 26).

ROUNDUP

Reactor News

AI SIGNS EPITHERMAL CONTRACT

A $5,354,000 research and development contract has been signed by Southwest Atomic Energy Associates and Atomics International for research on an epithermal thorium reactor (NU, Oct. '57, 21). The 15-firm Southwest group, being located in a low-cost fuel area, is seeking to leap-frog the first generation of reactor types to develop an advanced system with greater prospects for economic power. The present project is to determine the economic feasibility of using epithermal-range neutrons, and "may be followed by a test installation or a demonstration power plant, depending on the outcome of the research and development work." The concept contemplates use of U^{233} as fuel, sodium as coolant and, "if moderated," beryllium or graphite as moderator. "The nuclear power plant would be rated at ~200 Mw(e)," AI says of an eventual full-scale station.

NORTHERN STATES PICKS SITE

The 66-Mw(e) Allis-Chalmers advanced boiling water reactor Northern States Power and its 10 associated midwestern utilities will build is now set for 6 mi NE of Sioux Falls, S. D., on the banks of the Big Sioux river, as forecast (NU, Dec. '57, 27).

HRE-2 ON PRE-POWER TESTING

Operators of Oak Ridge's Homogeneous Reactor Experiment-2 have operated 80 hrs at zero power without difficulty, NUCLEONICS learns. They have completed measurements necessary to determine temperature coefficient over a range from 25 to 280° C, and are now shut down to seal up the container and demonstrate leak-tightness. Operation at full power will follow.

PROMISING NEW CONCEPT AT WESTINGHOUSE

Canadian Westinghouse last month announced it was ready to offer for sale a natural uranium, heavy water reactor it said—not without reservations—was capable of producing electricity in a 300-Mw(e) size for as little as 6.5 mills under Canadian financing practices, 10 mills in the U. S. The HPTR (horizontal pressure tube reactor) employs zirconium-clad fuel elements laid end-to-end in pressure tubes, high temperature D_2O coolant and low-temperature D_2O. High burn-up would be attained by replacing 5% of the fuel charge monthly, thus continually placing fresh fuel next to partly-used elements. Project engineers were at pains to point out that the cost figures were based to date only on paper studies, but insisted, "This is what we honestly feel can come out of this—possibly better." The Canadian Westinghouse study team made use of the know-how available to it from its U. S. parent.

OLIN CORES FROM MONTVILLE, CONN.

Assembly of reactor cores will start in May at Olin Mathieson Chemical Corp.'s new fuel plant at Montville, Conn. (NU, Oct. '57, 29), now half completed.

FIRST NEUTRONS AT WESTINGHOUSE CENTER

The Westinghouse Reactor Evaluation Center at Waltz Mill, Pa., came alive, nuclearly speaking, when a critical assembly testing a portion of the core being developed for the Yankee plant went critical. Also at the WREC site (NU, Aug. '57, 26) the Westinghouse Test Reactor is under construction, due for completion at year's end.

SEAWOLF TO GET WATER REACTOR THIS YEAR

Seawolf, the Navy's second nuclear sub, now operating at reduced efficiency because of heat exchanger troubles with her sodium-cooled reactor plant, (NU, Dec. '56, R3; March '57, R6; Aug., 26), will get a new pressurized-water reactor "within a year," Vice Adm. William V. Davis, Deputy Chief of Naval Operations, told a Nuclear Energy Writers Assn. meeting. The new unit, NUCLEONICS learns, will be Westinghouse-built.

EARTHQUAKE EFFECTS STUDY BEGUN

AEC has given Lockheed Missile Systems division of Lockheed Aircraft a $100,000, one-year contract to study the effects of earthquakes on reactors. Holmes & Narver, Los Angeles engineering firm, will participate as subcontractor. Effects on pressurized- and boiling-water reactors will be emphasized, with consideration given also to sodium-graphite, fast-breeder, gas-cooled and homogeneous types. Criteria will be developed for design requirements to eliminate or minimize hazards that might impair reactor operation or result in contamination. Results will be published in an AEC handbook.

WESTINGHOUSE ENGINE FOR SMALL SUB

A $1.5-million contract has gone to Westinghouse for condensers and propulsion motor, turbine generators and controls for the S2C small hunter-killer A-sub, for which Combustion Engineering is developing a small pressurized water reactor (NU, July '57, 68).

CLEVITE NOW AN MTR FUEL SUPPLIER

A contract for 300 replacement fuel elements for AEC's Materials Testing Reactor in Idaho has gone to Clevite Corp., Cleveland. The aluminum-clad, Al-U alloy elements are to be delivered over a 10-month period this year; Clevite plans to use new techniques in fuel-plate rolling and element assembly. The first commercial contract for MTR elements went to Babcock & Wilcox at the end of 1955 (NU, Dec. '15, 10; Jan. '56, 13). Clevite, which only entered the nuclear business in March 1957, says it is also making 350 enriched U-Al alloy plates for Westinghouse, 11,942 U plates for Argonne, and developing improved zirconium fabrication techniques.

PRATT & WHITNEY ANP CONTRACT RENEWED

AEC has renewed its contract with United Aircraft Corp. covering development of aircraft nuclear propulsion. The new ~$45-million pact extends one originally made in May 1953 until September 30, 1960, and provides for work costing an estimated $15-million/yr. Pratt & Whitney division of United Aircraft is working at the recently-completed Connecticut Aircraft Nuclear Engine Laboratory at Middletown, Conn., on designing an advanced plane propulsion system and developing reactor components. A parallel contract, from the Air Force, for development of the J-91 reactor-powered jet engine had earlier been canceled (NU, Dec. '57, 25).

VALLECITOS POWER BOOSTED

AEC has amended its operating license No. 1 issued to General Electric's Vallecitos boiling reactor to permit it to increase thermal level from 20 to 30 Mw, allowing a corresponding increase in electric output from 5 to 7.5 Mw(e). GE has successfully done this without adding fuel, thinks the reactor is capable of going yet higher (NU, Nov. '57, 23). A month earlier Argonne's Experimental Boiling Water Reactor had increased its power from 20 to 50 Mw(th) (NU, Jan. '58, 23).

News in Brief

C Stellarator Associates: RCA and Allis

Allis-Chalmers Mfg. Co. and Radio Corp. of America, who were chosen by AEC jointly to build and fabricate its "Model C Stellarator" (stellar generator) controlled fusion machine at the Project Matterhorn labs in Princeton, have formed a combined engineering staff organization to be known as C Stellarator Associates. About 50 persons, engineering and administrative, will be assigned by the two firms to the new unit. Project manager is Leonard P. Linde, A-C's director of electrical engineering; technical directors are Dane T. Scag of A-C and Philip T. Smith of RCA, both of whom have been working at Matterhorn for two years.

U-233 Specifications Declassified

AEC, which in November 1956 had announced a guaranteed fair price of $15/gm for U^{233} as uranyl nitrate, last month published specifications and detailed prices. Uranyl (233) nitrate in water solution, whose U-content is ~400gm/lit of solution, is to be delivered at Oak Ridge; metallic impurities may not exceed 5% by weight of total metallic content of solution; radiation level from fission product decay is not to exceed 1 mr/hr/gm of contained U; cross section of impurities for thermal neutrons is not to exceed 0.010 cm^2/gm U. The $15/gm price is reduced progressively as enrichment falls, as shown in table below:

Weight % ($U^{233} + U^{235}$) in total U	*$/gm ($U^{233} + U^{235}$)*	*$/gm total U*
100	15.00	15.00
95	15.00	14.25
90	14.96	13.46
80	14.90	11.92
70	14.84	10.39
60	14.77	8.86
50	14.69	7.35
40	14.58	5.83
30	14.41	4.32
20	14.12	2.82
10	13.40	1.34
5	12.24	0.61
1	6.64	0.07

Commercial Radiation Sterilization: Sutures

A new commercial radiation sterilization process was inaugurated Jan. 17 when Ethicon Inc. division of Johnson & Johnson began full-time commercial electron-beam sterilization of surgical catgut sutures. A High Voltage Engineering Corp. linear accelerator generating 7-million volts applies the cleansing dose to sealed containers of sutures on a conveyor belt at Somerville, N. J. Start of operations capped a ten-year, $1-million research project. Atomically-sterilized sutures promise faster healing and less tissue reaction for the patient, 8–14% greater tensile strength, greater pliability and ten times greater safety margin for the surgeon, as against heat-sterilized catgut.

AEC Extends Indemnity to Contractors

AEC will offer statutory indemnity, provided by Congress last summer, to its major contractors to protect them and the public against nuclear accident losses. The offer applies to AEC prime contractors and their subcontractors engaged in operation of reactors or other facilities such as chemical separation plants, as well as design and engineering contractors and suppliers of components. Those accepting the offer will be indemnified up to $500-million against claims resulting from nuclear accidents; they—and the public—will get much broader protection than is provided in existing AEC contracts, which do not cover accidents caused by fault or negligence of a subcontractor or supplier. Cost of the indemnity will not be charged to AEC contractors, but regulations requiring licensees to obtain commercial insurance and pay for their governmental indemnity remain unchanged.

Nuclear Power Lab for Allis-Chalmers

Allis-Chalmers will build a 23,000 sq ft lab near Milwaukee for reactor plant research, development and engineering and construction and testing of models and prototypes of reactors and components. The lab will house 150–200 scientists, engineers, draftsmen and technicians, plus electronic computers.

AEC Closing Boron-10 Plant

The boron-10 plant near Niagara Falls operated for AEC by Hooker Electrochemical Co. is being shut down and placed on standby, following an AEC study showing current inventory of the neutron-absorbent material to be sufficient to meet the demand "for the next several years." The plant, which separates boron-10 from boron-11 (NU, March '57, R6), will be completely shut down by July 1. It was built only in 1953.

New Giant in A-Metals Field

Claiming to be the world's largest fabricators of precious metals (ranging from gold, silver, platinum and iridium to uranium and zirconium), Engelhard Industries Inc., a diversified giant with annual sales of $200-million, was born Jan. 3 as result of consolidation of nine companies. Among the members of the new family are Baker & Co., whose interest is in cold uranium scrap and in chemical reprocessing; D. E. Makepeace, which has just completed a $1-million plant at Plainville, Mass., for fabrication of fuel elements and reactor components (NU, May '57, 26); and Nuclear Corp. of America, consultants and makers of nuclear instruments.

Big U-Contract at Kermac

Kermac Nuclear Fuels will collect $300-million minimum, $350-million maximum, under its ten-year contract to supply uranium concentrates from its 3,300 tons/day mill to AEC, says Dean A. McGee. The president of Kermac's parent firm, Kerr-McGee Oil Industries, also told the Washington Society of Investment Analysts that known U reserves in the U. S. (of which his firm is the largest holder) are relatively small in terms of what will be discovered as the demand grows. "We think there will be many additional areas of the U. S. able to produce uranium," he predicted.

Clue to Cheap Waste Disposal?

General Electric chemists at Hanford see "globs of custard-like gel" as a possible answer to the problem of radioactive waste disposal. They hope to use sodium silicate—which, when mixed with a solution containing aluminum, solidifies into a milky white gel—to capture cesium-137 and strontium-90. Aluminum from dissolved cladding is present in liquid refuse from Hanford's chemical separations plants. If successful, the technique would permit burial of globs of gelled waste, eliminating the need for large costly steel tanks. Decay heat turns the gel to a clay-like substance or, if the temperature is high enough, to a porcelaneous material, fixing the waste.

Vitro Sees $3-Billion A-Market Abroad

A Vitro Corp. analysis of nuclear needs outside the U. S. through 1967 shows a $3,115,000,000 total potential market. Broken down, Vitro sees a $2-billion market for power reactors and related equipment, $1-billion for propulsion reactors, $30-million in research reactors, $10-million in radioisotope and radiation applications, and $75-million in engineering services. Most overseas nations are in the early phases of their nuclear development, points out Vitro International vice-president Ralph L. Brown; some of them are faced with an immediate need for nuclear power and having no time to develop their own technological capabilities must rely on the U. S. to fill the gap.

Three More Navy A-Subs To Fire Ballistic Missile

The Navy got swift approval from Congress for its 20th, 21st and 22nd nuclear submarines. Contrary to widely-stated accounts, these will not be the first missile-firing A-subs —four carrying Regulus *guided* missiles are on the way; but they will be the first armed with Polaris *ballistic* missiles. Westinghouse promptly got an $18-million contract for their reactor vessels, heat exchangers, pressurizers, main pumps, instrumentation, etc. The Navy is considering asking for six more.

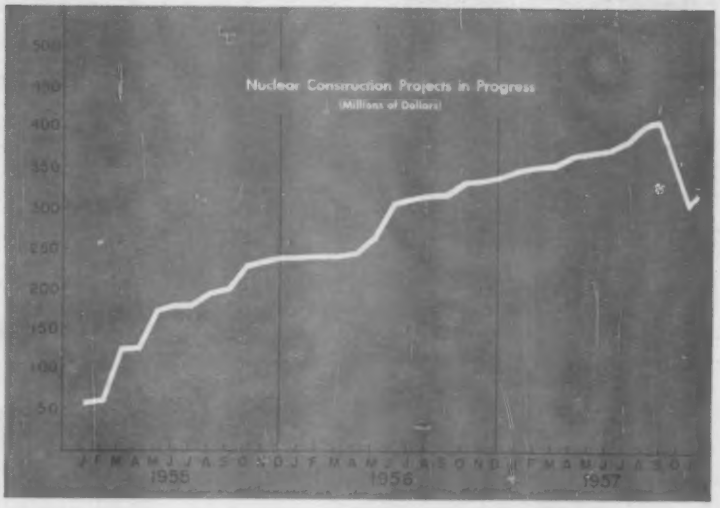
Socony Irradiation Lab Includes Unique Hot Cell

Socony Mobil Oil Co. has invited bids from six construction firms to build its projected radiation laboratory at Pennington, N. J. Company officials said the lab would feature a unique, combination wet-and-dry hot cell for work with fuel elements and CO^{60}. The cell could be flooded with water for flexibility of experimentation. The Socony Mobil lab will be interdependent with the larger, 10-company nuclear research center under construction at Plainsboro, N. J. (NU, Aug. '57, 104). Bids are due Feb. 17.

Flood of Technical Papers Submitted for Geneva Parley

More than 1,300 papers have been submitted to AEC for the second Atoms-for-Peace conference in Geneva, Sept. 1–13. Several hundred will be selected to make up the U. S. technical presentation.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts*—			
Contracts awarded for federal projects (10^3)	4,183	3,354	3,828
Proposed construction, privately-owned (10^3)	3,500	17,000	300
Contracts awarded, private work (10^3)	500	30,500	0
Backlog of private projects (10^6)	247	243	168
Access Permits†—			
Access permits issued	17	25	32
Total access permit holders	1,404	1,396	1,145
Isotope Use†—			
Applications for isotope use	438	339	527
Cumulative total of isotope users	3,392	3,335	3,663
Oak Ridge National Laboratory shipments	1,134	1,134	989
Public and private export shipments	222	167	194
Employment†—			
AEC employment	6,808	6,832	6,636
Construction and design contractors' employment	11,692	11,627	15,129
Total operating contractors' employment	97,195	97,925	93,476
Production workers	50,294	50,285	49,980
Research and development employees	40,741	41,305	37,593
Miscellaneous workers	6,160	6,335	5,903

	Operating	Building	Contracted
U. S.-built Reactors‡—			
Power, domestic	1¶	4	8
Power, for export	0	1	5
Power experiments and pilot plants	7	3	3
Military and naval	5	20	10
Research and test, domestic	41	26	38
Research and test, for export	7	14	4
Foreign-built Reactors‡—			
Power, domestic	4	24	12
Power, for export	0	0	2
Research and test, domestic	25	17	6
Research and test, for export	3	9	1

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures
¶ Appears to be down one from last month because Vallecitos boiling reactor is reclassified as a pilot plant.

New Instrument News

Operation and Selection of "RCLiac" Scaler-Analyzers

General Description

The "RCLiac" scaler-analyzers are innovations to nuclear data processing. Nuclear detector pulses are processed and quantized in total or in spectra.

Operation and Application

Two basic modes of operation yield extensive applications in the laboratory. Gross counting, the scaler mode of operation, affords events-per-interval-of-time or time-per-event analysis. Time intervals or event totals may be preset. Simple applications in this mode of operation are: half-life determination, pulsed reactor response, fast-neutron velocity distribution, and other similar studies. With the aid of an automatic sample changer, as many samples as there are channels can be counted, automatically.

The spectrometry mode of operation allows background reduction, smaller tracer doses, isotope identification, complex spectral distribution analysis and other related analyes.

With their inherent versatility of operation and application the RCLiacs are believed to be destined to become as universally accepted in the nuclear field as the oscilliscope is in the electronic field.

Readout

The RCLiacs have two basic readout modes, "Curve" and "Number". "Curve" readout plots graphically the total count recorded in each channel. "Number" readout displays the arithmetic total of counts received in each channel in decimal Arabic form. Both RCLiac models have switch-selected "Curve-Number" readout displayed on a cathode-ray tube which presents a photographic image for rapid and accurate recording of data for permanent reference.

Design

Reliability, precision and ease of operation have been designed into the RCLiacs. Design features which contribute to these parameters of operation are: 95% transistorization affording greater reliability and lower power requirements, printed circuitry throughout and modular construction affording unique adaptions for specific situations. Yet the RCLiacs are remarkably small in size and weight, actually portable.

Selection

Selection of your RCLiac should be based primarily on your facility's basic research requirements. For the modest laboratory the RCLiac-32 should be considered, while larger installations may require the RCLiac-128. The RCLiac-128 has four times the range of the RCLiac-32, affording a greater energy range in the spectrometry mode and a greater range of operation in the gross counting mode.

The finest spectrometry instrument now in use is the RCL 256-channel analyzer, the most widely accepted instrument for pulse-height analysis.

Your RCL representative can offer excellent counsel and help you in the proper selection of the right RCLiac for you. Write today for more detailed information on the RCLiacs and a list of representatives near you.

Introducing

RCLiac-32 and 128

transitorized multi-channel scaler-analyzer data processing systems

One instrument that performs all operations from detection to qualitative or quantitative analysis. All counting and analytical operations from simple gross counting through scintillation spectroscopy and pulse-height analysis can be accurately and rapidly processed by the RCLiacs. Representative features:

- Six plug-in modules
- Super-stable H.V. supply, continuously variable from 500 to 1500 volts
- Completely transistorized linear amplifier
- Preset time from 0.1 second to several days
- Preset count from 10 to several billion
- Maximum zero drift: ⅓ channel per day on RCLiac-32
  1 channel per day on RCLiac-128
- Maximum input pulse rate: 50,000 pps.
- Data stored in decimal form
- One million count capacity per channel
- Readout is "live" during accumulation in either "curve" or "number" mode
- Instant, permanent recording of data by use of Polaroid camera
- Outputs available for strip chart recorder and digital printer.

Atomfair Visitors

See the remarkable RCLiac-32 in operation at RCL's booth. Also see instruments representative of the complete line of nuclear instrumentation from RCL.

© **Radiation Counter Laboratories, Inc.**

NUCLEONIC PARK, SKOKIE, ILLINOIS

Radiation Counter Laboratories, Inc. Dept 128
Nucleonics Park, Skokie, Ill.

Gentlemen,

Please send me information on the ☐ RCLiac-32, ☐ RCLiac-128, ☐ RCL's 256 Channel Analyzer.

Name_____

Address_____

City_____ State_____

rigid specifications

Tension tests are required to be made at room temperatures and at 670° F. The following minimum physical properties shall be met:

At Room Temperature:

TS	YS	EL	RA	CHARPY V-NOTCH
70,000	30,000	45	50	50

At 670° F. the minimum tensile strength shall be 51,000 p.s.i. and the minimum yield strength 18,300 p.s.i.

Rejection

Each casting that develops unacceptable defects during shop working or fails to conform to all of the requirements of these specifications shall be rejected. No repair by welding or other means will be permitted.

Radiographic Inspection

(a) Paragraph S5 (a) of the Supplementary requirements of ASTM-A 362-52T.

(b) All castings shall be radiographed 100% and shall conform to ASTM-E7 1-52, Class 2 quality, except as modified by these specifications.

(c) The manufacturer shall establish a positive system of identification of the X-ray plates which shall be subject to approval by the inspector. This system shall guarantee complete coverage by radiographing and provide for positive identification between the plate and the subject.

Inspection of Penetrants

All castings shall be subjected to inspection by fluorescent penetrants or penetrating dyes both inside and out. All cracks, porosity, or flaws revealed as a result of the Dye Penetrant Test shall be due cause for rejection of the casting.

All cast pipe shall be hydrostatically tested to 5,900 p.s.i. and held at that pressure for 20 minutes with zero pipe leakage. Each length of pipe shall be hydrostatically tested at the manufacturer's plant.

The 304L stainless steel shall conform to the following ladle analysis:

Carbon	.03 max.		
Manganese	1.50% max.		
Phosphorous	.03% max.		
Sulphur	.03% max.		
Silicon	2.00% max.		
Chromium	18.00	-	21.00%
Nickel	8.00	-	11.00%

Pipe: All pipe of the following sizes shall be centrifugally cast stainless steel as per ASTM-A 362-52T, except as modified by these specifications:

16" - Sch. #160
12" - Sch. #160
10" - Sch. #160
8" - Sch. #140

All pipe shall be machine finished to 125 micro-inch interior and exterior.

for nuclear piping met by U.S. PIPE metal mold process

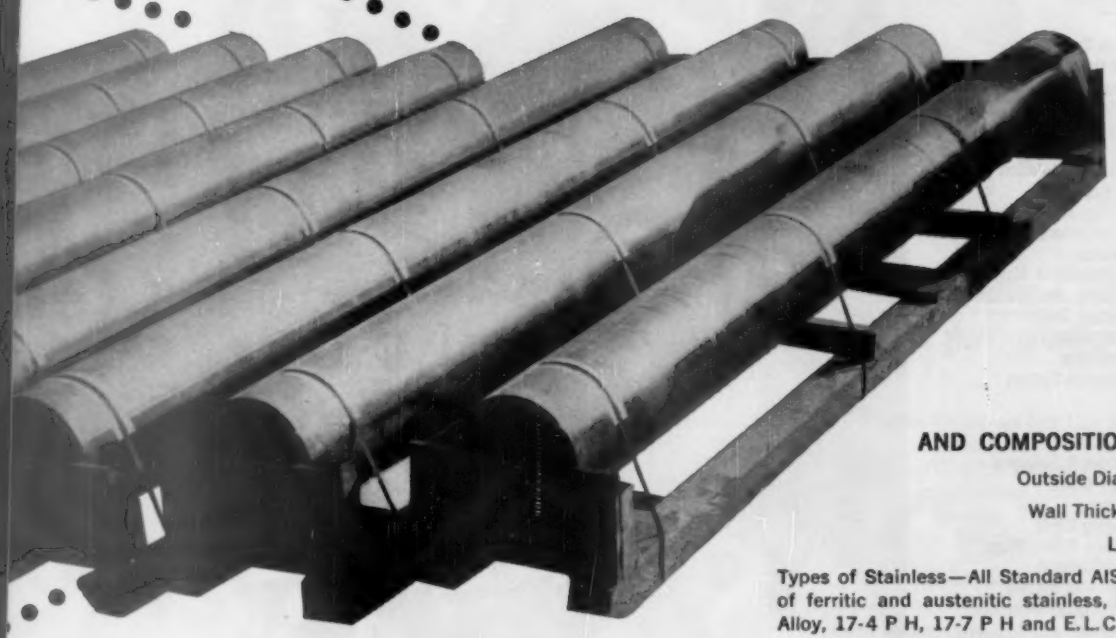
Centrifugally Cast Stainless Steel Solves Many Piping Problems

Combinations of temperatures, pressures and corrosive conditions never encountered before: these are among the piping problems that must be overcome by the men who design the nation's nuclear power installations.

Stainless steel centrifugally cast pipe provides many of the answers. Study the specifications at the left . . . specifications demanded of stainless steel pipe on a recent job for Paul Hardeman, Inc., Los Angeles, California. This pipe is being used for heavy duty, high pressure, elevated temperature service in the primary piping system of the SPERT-III Reactor at the U.S. Atomic Energy Commission's National Reactor Testing Station near Idaho Falls, Idaho. The Stearns-Roger Mfg. Company, Denver, Colorado, is the architect-engineer on this project. A complete tabulation of the actual test data obtained on this pipe and to this specification is available upon request.

U.S. Pipe is headquarters for metal mold centrifugally cast alloy and stainless steel pressure pipe over a wide range of special and standard analyses—in large and small quantities—and to individual specifications.

If piping of the type described above is the bottleneck in your nuclear power planning, write and outline the problem.



SIZE RANGE AND COMPOSITION FLEXIBILITY

Outside Diameter—6" to 50"

Wall Thickness—⅜" and up

Length—Up to 16'

Types of Stainless—All Standard AISI and ACI grades of ferritic and austenitic stainless, including No. 20 Alloy, 17-4 P H, 17-7 P H and E.L.C. grades.

UNITED STATES PIPE & FOUNDRY CO.

Steel and Tubes Division

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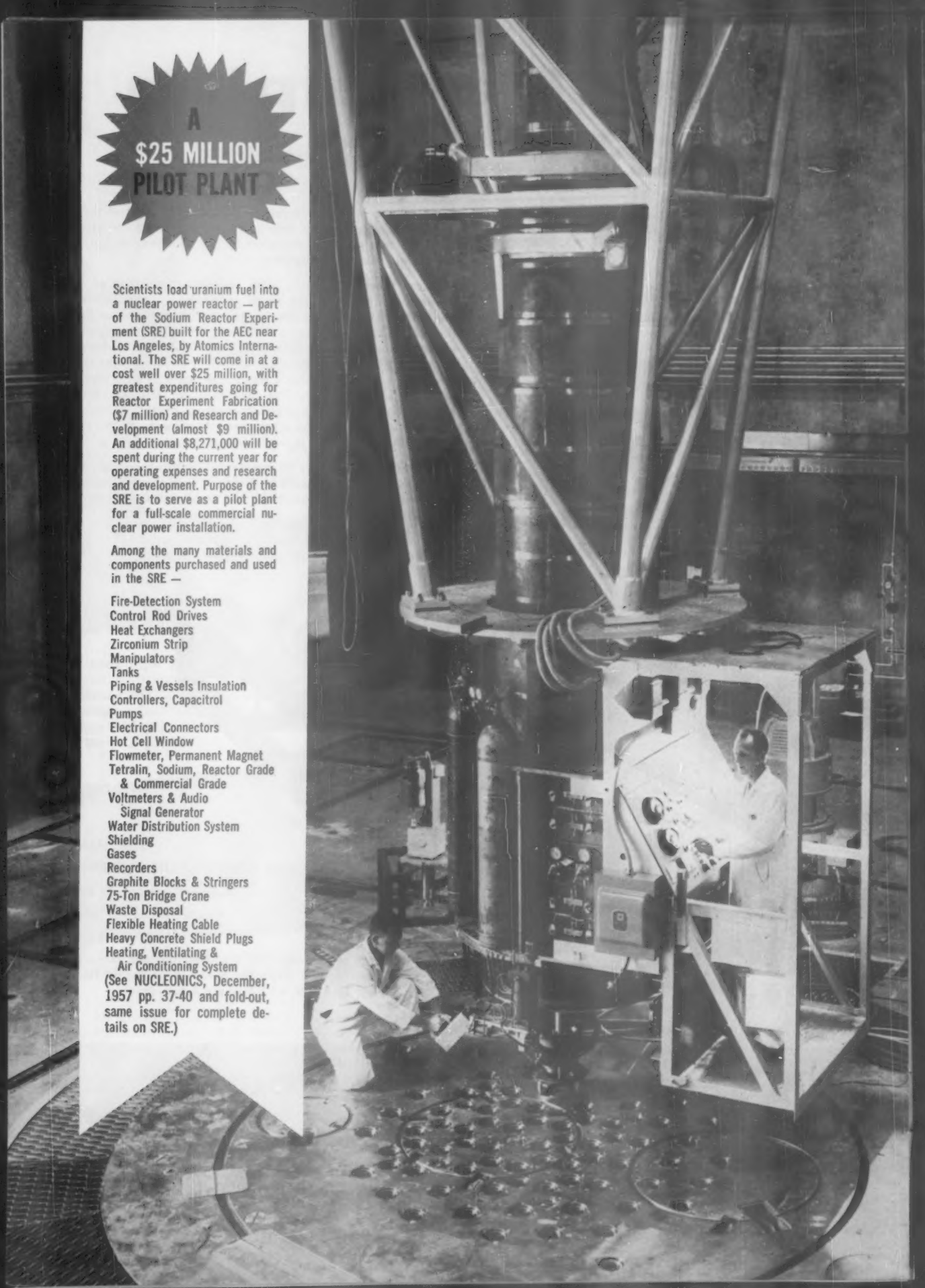

A $25 MILLION PILOT PLANT

Scientists load uranium fuel into a nuclear power reactor — part of the Sodium Reactor Experiment (SRE) built for the AEC near Los Angeles, by Atomics International. The SRE will come in at a cost well over $25 million, with greatest expenditures going for Reactor Experiment Fabrication ($7 million) and Research and Development (almost $9 million). An additional $8,271,000 will be spent during the current year for operating expenses and research and development. Purpose of the SRE is to serve as a pilot plant for a full-scale commercial nuclear power installation.

Among the many materials and components purchased and used in the SRE —

Fire-Detection System
Control Rod Drives
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(See NUCLEONICS, December, 1957 pp. 37-40 and fold-out, same issue for complete details on SRE.)

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Yet expansion into commercial electric power is but one of the tremendous growth areas for the nuclear industry . . . the industry that's sold on – and by – **NUCLEONICS** magazine, the only publication listed as being exclusively in the field in "Business Publication Rates And Data."

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ABC ABP

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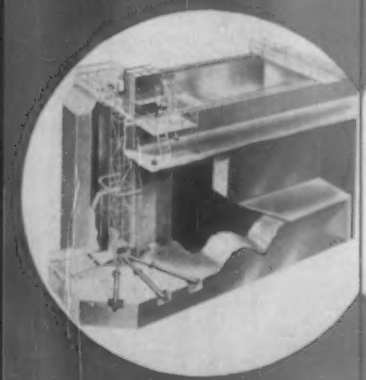
reactor diversification and reliable design ...

Unlike other builders of nuclear reactors who specialize in specific types — ACF has achieved prominence through diversification. This diversification is a tribute to the range and depth of our scientific, engineering and manufacturing skills. As a result of our field proven designs — today we offer a group of "standard reactors". The ACF Heavy Water Tank Type standard reactor is the direct result of the experience gained with the MIT reactor, the Italian National Committee reactor in Italy and other designs recently completed for government and private organizations. By combining the best features of each of these installations ACF is ready to offer a standard Heavy Water Tank Type research reactor with power levels ranging from 1000 KW to 10,000 KW.

Another standardized reactor is the ACF Light Water Tank Type—based on the best design features of 4 similar units now under construction in the U.S., Holland and Sweden with power outputs ranging from 10,000 KW to 30,000 KW. Used primarily for materials testing and engineering development, these units are further evidence of ACF's established pattern of reliability in reactor design and construction.

Two ACF Power Reactor Designs have recently been completed — one the Boiling Water Reactor Type and the other the Gas Cooled Type. The ACF approach to power reactor construction is based on the use of **proven** engineering and **sound** design to provide the customer with the most economic solution of his problem with **existing** technology.

LIGHT WATER POOL TYPE | HEAVY WATER TANK TYPE | LIGHT WATER TANK TYPE | PROCESS HEAT



based on experience

Other new design developments at ACF include the Process Heat Reactor and the complete line of Pool Training Reactors as announced recently.
Reactors from a 1 watt trainer to 150,000 TKW power unit have already been designed by ACF. No matter what your requirements are in the area of nuclear reactors, the diversification, experienced personnel and proven designs found at ACF are your best assurance that we have a sound technical and economic approach to your problem. We are free at any time to undertake exploratory discussions. Write to us, or see us at our Booth at the Atom Fair March 16-21.

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NUCLEAR PRODUCTS-ERCO

Division of ACF Industries Incorporated

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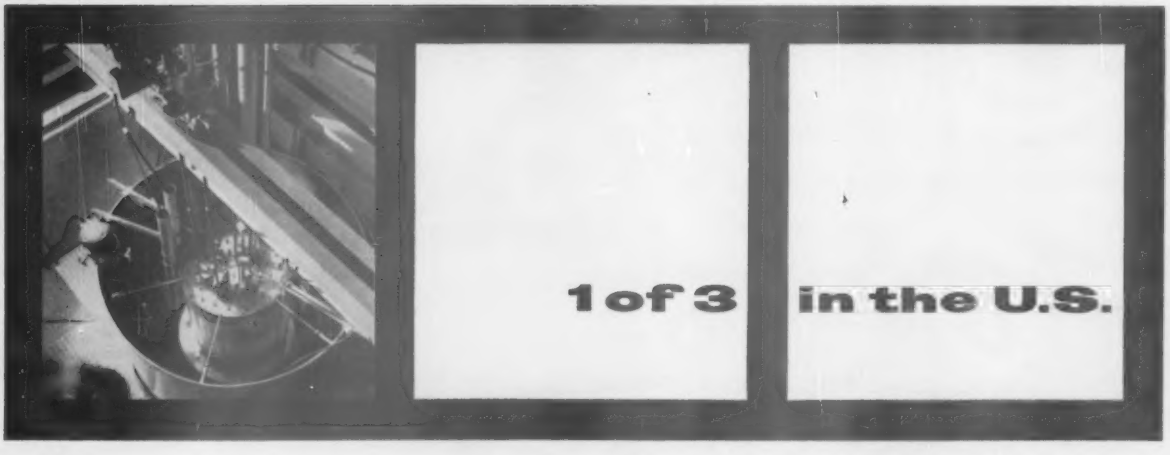
On December 10, 1957, Martin officially commenced operation of an important new facility in the field of nuclear research and development.

This was the date of criticality of the Martin Nuclear Experiment Facility – one of only three privately owned and operated critical test installations in the United States. Martin activities in the nuclear field now are in their fourth year. The new facility is the result of a long-range program for the establishment of complete research and testing capabilities to augment the development and manufacturing assets of a fully integrated Nuclear Division.



Martin nuclear activities encompass the research, development, manufacturing and testing of reactors, fuel elements and related components for industry, the Atomic Energy Commission and all branches of the military.

(Photo above) Now under zero power test at the facility is a full core of stainless steel tubular fuel elements for the MARTIN Air Transportable Power Reactor.

MARTIN
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We'll be glad to help you if we can (chances are good)

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it has to do with Picker x-ray

HIGH PURITY RARE EARTHS

Available in quantities at surprisingly low cost

a report by LINDSAY

A few months ago, in one of these reports, we presented this table of high purity rare earth and yttrium oxides. We anticipated inquiries, of course, but the flood of letters requesting detailed information really startled us.

What interests us particularly, and will you, is the fact that so many research people are intrigued with the practical possibilities of these unique materials. The large amount of research now being done on high purity rare earth oxides in a wide variety of industries encourages us to suggest the likelihood that they may offer you opportunities for potentially profitable investigation.

Already, in a little more than two years since rare earths in purities up to 99.99% became available in commercial quantities, they are being used as basic production materials in many chemical and industrial operations.

Production Up—Costs Down

We have expanded our production facilities to keep up with demand and now have more than 100 ion exchange columns in continuous operation. Quantities are large enough to assure you a dependable source of supply. Prices are low enough to make their use on a production basis economically sound.

Most of the high purity rare earth and yttrium oxides are available for prompt deliveries in quantities of an ounce to hundreds of pounds.

We can't tell you how to use high purity rare earths in your production operations, nor can we promise that one of them may be the missing element in new process or product developments on which you are working. We *can*, however, supply you with data which you will find interesting, revealing and quite possibly of immediate importance to you.

TYPICAL MAXIMUM IMPURITIES IN LINDSAY PURIFIED RARE EARTH AND YTTRIUM OXIDES

ATOMIC NO.	OXIDE	CODE	PURITY	% RARE EARTH MAXIMUM IMPURITIES AS OXIDES
57	La_2O_3. LANTHANUM OXIDE	528 529	99.99 99.997	0.01 Pr, 0.001 Ce. 0.0025 Pr, 0.0005 others
58	CeO_2. CERIC OXIDE	215 216	99.8 99.9	0.2 (largely La + Pr + Nd). 0.1 (largely La + Pr + Nd).
59	Pr_6O_{11}. PRASEODYMIUM OXIDE	726 729.9	99 99.9	1 La + Nd + smaller amounts of Ce and Sm. 0.1 Ce + Nd.
60	Nd_2O_3. NEODYMIUM OXIDE	628 629 629.9	95 99 99.9	1-4 Pr, 1-4 Sm, 0.5-1 others. 0.1-0.4 Pr + 0.1-0.4 Sm + 0.5 others. 0.1 (largely Pr + Sm).
62	Sm_2O_3. SAMARIUM OXIDE	822 823	99 99.9	0.2-0.7 Gd, 0.2-0.6 Eu, and smaller amounts of others. 0.1 (largely Nd + Gd + Eu).
63	Eu_2O_3. EUROPIUM OXIDE	1012 1011	98-99 99.8	1-2 Sm + smaller amounts of Nd + Gd + others. 0.2 (largely Sm + Gd + Nd).
64	Gd_2O_3. GADOLINIUM OXIDE	928.9 929.9	99 99.9	1 Sm + Eu + trace Tb. 0.1 Sm + Eu + trace Tb.
65	Tb_4O_7. TERBIUM OXIDE	1803 1805	99 99.9	1 Gd + Dy + Y. 0.1 Gd + Dy + Y.
66	Dy_2O_3. DYSPROSIUM OXIDE	1703 1705	99 99.9	1 (largely Ho + Y + Tb + small amounts of others). 0.1 Ho + Y + traces of others.
67	Ho_2O_3. HOLMIUM OXIDE	1603 1605	99 99.9	1 (largely Er + Dy + small amounts of others). 0.1 Er + Dy + traces of others.
68	Er_2O_3. ERBIUM OXIDE	1303 1305	99 99.9	1 Ho + Dy + traces Yb and Y. 0.1 Ho + Tm.
69	Tm_2O_3. THULIUM OXIDE	1405 1403	99.9 99	0.1 Er + Yb + trace Lu. 1 Er + Yb + trace Lu
70	Yb_2O_3. YTTERBIUM OXIDE	1201 1202	99 99.9	1 Er + Tm + trace Lu. 0.1 Tm + trace Lu + Er.
71	Lu_2O_3. LUTETIUM OXIDE	1503 1505	99 99.9	1 Yb + Tm + traces of others. 0.1 Yb + Tm + traces of others.
39	Y_2O_3. YTTRIUM OXIDE	1112 1115 1116	99 99.9 99.9+	1 Dy + Gd + traces Tb and others. 0.1 Dy + Gd + traces Tb Approx. 0.05 Dy + Gd.

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Honeywell's Reactor Simulator responds like a low-power research type reactor, and will cover a range of 0-150 percent of reactor design power. All amplifiers, recorders and control instruments are operative, and are the same as those used in actual reactors.

For *realistic* reactor training

. . . Honeywell's Reactor Simulator

Here's the practical approach to reactor training. This Simulator is an analog of a functioning reactor—complete with full-size control, recording and safety systems exactly like those used in current research reactor installations. It accurately reproduces important reactor functions, substituting electronic response for nuclear reactions.

In designing the Simulator, Honeywell has applied its broad experience in planning and manufacturing actual packaged reactor control systems. This experience is combined with a rigid quality standard that makes the Simulator a highly flexible and accurate training instrument.

The Simulator faithfully reproduces important reactor functions, is compact and simple—offers high performance at low cost.

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H HONEYWELL *First in Controls*

NEW CHALK RIVER FUEL ELEMENT IS BUILT TO LAST LONGER!

SYLCOR fuel element for the new Chalk River MTR reactor is made of 93% enriched uranium-aluminum alloy clad in aluminum. Each of ten plates contains 14 grams of U^{235}—a total charge of 140 grams in each standard element.

Slow fuel burn-up made long life a major consideration in the design and fabrication of the fuel elements for the new Materials Testing Reactor recently built by Atomic Energy of Canada at Chalk River, Ontario.

It was estimated that the elements would not have to be replaced for a long time if they were precision-fabricated to withstand the heat and corrosion factors within the reactor.

To meet these requirements SYLCOR scientists and engineers developed new techniques of fabrication that fulfilled the rigid specifications of manufacture necessary to give the fuel elements long life.

The 10 fuel plates of each 3-foot element are joined to their side plates by new precision brazing techniques, giving the element greater over-all uniform strength. The end adapter for each SYLCOR fuel element was machined from aluminum bar stock to give greater structural integrity than could be attained from conventional sand-casting methods. Exacting methods of manufacture were employed to keep certain tolerances as close as + .001 of an inch.

The recent delivery of the Chalk River order of SYLCOR fuel elements marked the first foreign shipment of highly enriched fuel elements—a major step in the program of international cooperation among the world's peaceful nations to explore and utilize the limitless commercial uses of the atom.

Our combined scientific, engineering and technical staff will be glad to help you solve any problems you may have in the application of nuclear fuel—whether immediate or in the planning stage. For information write: Sylvania-Corning Nuclear Corp., Bayside, N. Y.

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ACHIEVEMENT

Above
Precision winding of a coil section for the Beta-ray Spectrometer constructed by CANADAIR for Atomic Energy of Canada Limited, at Chalk River, Ontario.

At right
Beta-ray Spectrometer being prepared for shipment.

CA58-NU 24 UST

Canadair's Nuclear Division has successfully applied its engineering and development facilities to the design and construction of the Coils for the generation of the magnetic field in a large Beta-ray spectrometer recently delivered to Atomic Energy of Canada Limited. The spectrometer is used to determine the energy spectrum of Beta-rays emitted from radioactive sources. The large source area, good resolution and high transmission of this $\pi\sqrt{2}$, iron-free, double-focusing spectrometer provide the opportunity of making measurements not previously possible in the field of Beta-ray spectroscopy.

The comprehensive range and accuracy of this spectrometer are in large part the result of adherence to extremely close dimensional tolerances by Canadair's team of nuclear scientists and engineers. Moreover the electrical insulation requirements demanded rigorous control of environment and workmanship.

Canadair designs and manufactures reactors and their components, as well as specialised physics instruments to most exacting specifications: its nuclear division is always available for advice on problems and invites your enquiries.

Write P.O. Box 6087, Montreal, P.Q. for the booklet "CANADAIR IN THE FIELD OF NUCLEONICS".

Nuclear Division

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• Aircraft • Guided Missiles • Research and Development • Nuclear Engineering

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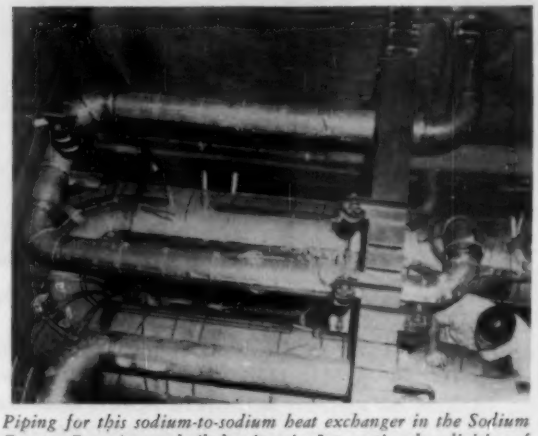
Have a king-size problem in nuclear piping?
TUBE TURNS can help you!

The fitting shown above has the heaviest wall ever forged... over 4" thick... another first by Tube Turns. Here is another example of the broad experience of Tube Turns' engineers and craftsmen in the solving of problems in super-critical piping service. This pioneering know-how covers all kinds of nuclear projects... all types of piping metals and alloys... all sizes of fittings.

When you bring your piping problems to Tube Turns, you take advantage of this experience and leadership in nuclear piping which dates back to the Manhattan Project. We're at your service!



Piping for this sodium-to-sodium heat exchanger in the Sodium Reactor Experiment, built by Atomics International, a division of North American Aviation, Inc., employs TUBE-TURN* *Fittings for changes in direction.*

*"TUBE-TURN" and "tt" Reg. U.S. Pat. Off.

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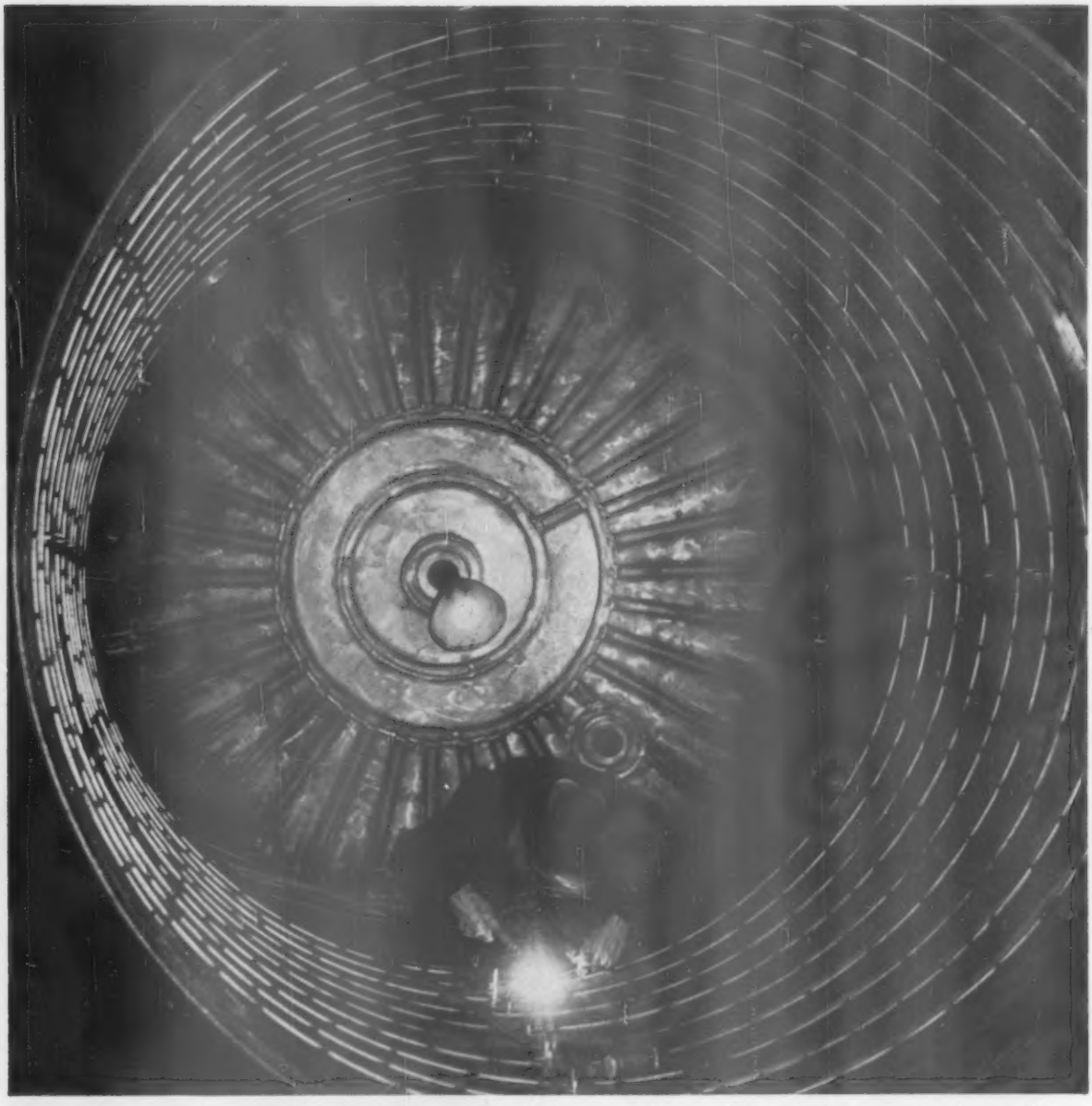

A Reactor That Won't React — To Corrosion!

Designed for 300 psig at 450F, this reactor will be subjected to unusually corrosive service. Hastelloy, a non-ferrous nickel-base alloy, was specified to line the vessel. The ASME Code shell was first lined with narrow strips and segments by manual metallic-arc welding. Then the welds were covered by cap strips, heliarc-welded to the liner. Multiple tests confirmed the excellence of the welds. Manually welding so many feet of alloy called for the most skilled craftsmanship—the type of craftsmanship Graver has characteristically applied to alloy fabrication for years. When custom-crafted vessels in special alloys are the answer to your corrosion problem, calling in Graver assures quality fabrication, long life and dependable service.

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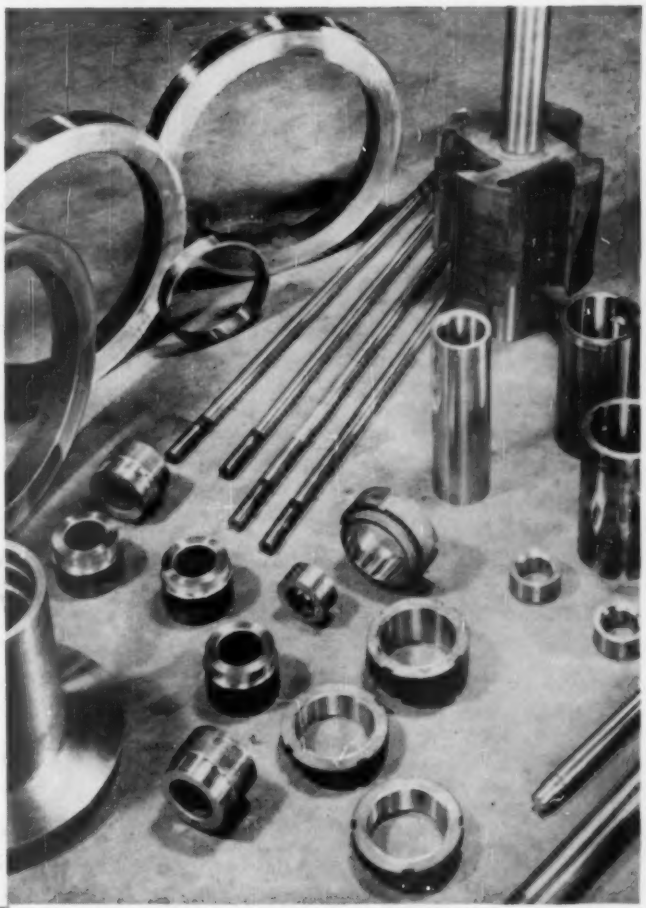

The superior physical properties of Cleveland Hard Facing Components assure dependable long life service . . . reduce equipment downtime and lower maintenance costs.

Take advantage of these outstanding characteristics.

- *Corrosion Resistance* — Resists most corrosive acids and oxides.
- *High Strength* — Offers high compressive strength up to 256,000 psi. Good flat impact and high hot strength.
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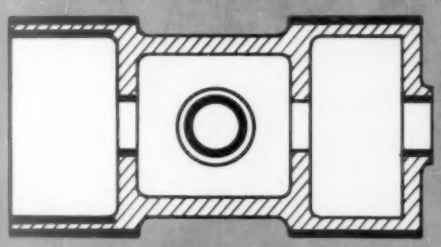
- *Economical* — Applied only to points requiring maximum protection, Hard Facing gives low cost protection that increases component life.

Typical Hard Faced parts include rods, valves, rotary blades, gears, splines, shafts, pump shafts, pins, rings, seals and many others.



Heavy lines indicate typical areas of hard facing overlays.

How It Is Done

As the cross-section drawing shows, a 1/16″ of the original base metal is removed at all points requiring special wear, heat or corrosion resistant properties. The metal is then replaced with the selected alloy — usually a high cobalt-chrome-tungsten type — using one of the following processes — Submerged Arc, Heliarc, Manual or Automatic Gas Welding.

WRITE FOR COMPLETE DETAILS

Cleveland Hard Facing, Inc.

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Pressurizer for designed with stainless

The reactor we are talking about contains a fissionable nuclear core through which passes thousands of gallons of water per minute at elevated temperature and pressure. This pressurized radioactive water transfers heat from the reactor core to a shell-and-tube-type steam generator which in turn produces non-radioactive steam in the secondary system for power turbine operation.

As power requirements change, the temperature of the primary water is maintained by moving neutron-absorbing reactor control rods in or out of the reactor. Resulting pressure and volumetric changes of the primary water system must be controlled, and this is the job of the pressurizer vessel.

When the primary system water pressure drops, high-capacity back-up immersion heaters at the bottom of the pressurizer go into action to heat the water and generate more steam and maintain pressure. When the primary system pressure goes *up*, water sprays inside the pressurizer are activated to collapse the steam bubble, thus reducing the pressure and permitting positive water surges from the primary system. Since the walls are alternately exposed to wetted and vaporous conditions at high temperatures, a severely corrosive environment exists. Corrosion in this vessel could result in a hazardous level of radioactivity throughout the primary side of the plant. The choice of a proper steel to insure against this hazard was a major consideration. This is why the pressurizer was designed with stainless steel.

Electric furnace and metallurgical staffs worked together to obtain the precise chemical composition specified. Great care was taken during processing in the electric furnace shop. Then, forge press crews, heat treaters and machinists combined skills to produce the finished rings, which certainly rank among the finest USS Quality Forgings ever produced.

Your USS Quality Forging order makes use of the same steel-making facilities, the same processing equipment, and most important: your forging is made by the same skilled workmen in our Homestead Forgings Division.

If you'd like to inquire about a USS Quality Forging made under these conditions, or if you'd like our free 32-page booklet on the subject, please write to United States Steel, 525 William Penn Place, Pittsburgh 30, Pa.

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nuclear reactor system steel USS Quality Forgings

How your truth dollars help keep the Reds in the red

• The truth dollars you give to Radio Free Europe help keep truth on the air behind the Iron Curtain.

And the truth is an enormously disruptive force to the Reds. For it keeps their captive people thinking . . . wondering . . . and less than completely dominated. The truth keeps needling the Reds. Breaks through their monopoly of lies. Keeps them unsure. Off balance. And thus the truth keeps up to forty fully armed Red divisions tied up policing Russia's satellite countries. Forty divisions, mind you, that might otherwise be put to more aggressive use elsewhere . . . and who knows where?

Your truth dollars keep the 29 super-powered transmitters of the Radio Free Europe network on the air . . . broadcasting the truth behind the Iron Curtain . . . every hour of every day.

Why *your* truth dollars?

Because Radio Free Europe is a private, non-profit organization supported by the voluntary contributions of American business and the American people. And *your* dollars are urgently needed to keep it on the air . . . to help operate its transmitters, pay for its equipment and supplies, and its scores of announcers and news analysts in 5 languages.

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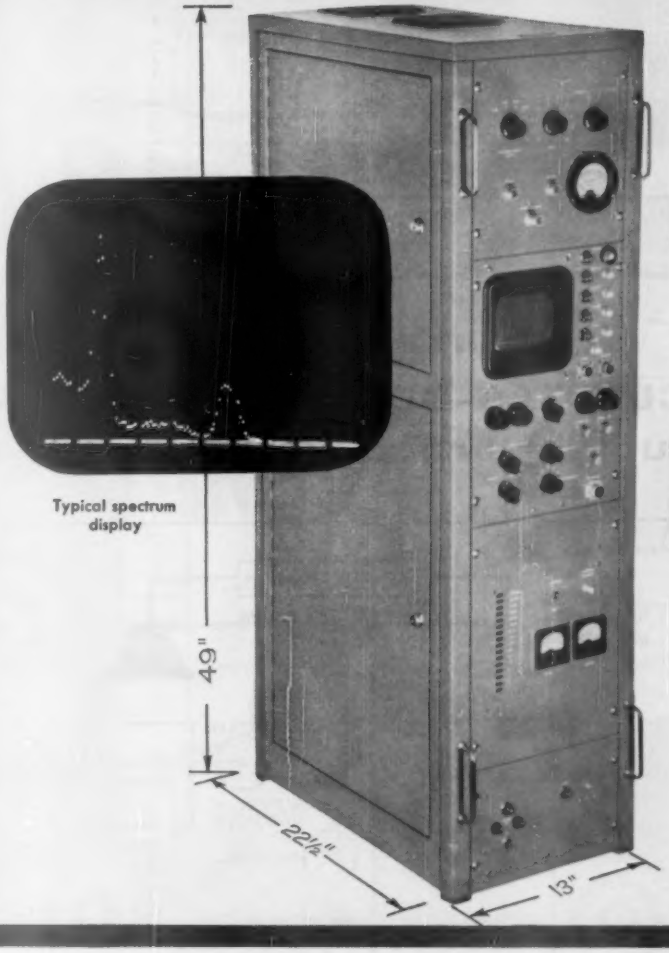

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- Unit construction
- Semi-portable (150 lbs.)

VERSATILE DATA PRESENTATION

- Oscilloscope display
- Binary count manual readout
- Accessory readout devices: photo recording camera, strip chart recorder, electric typewriter, punch tape

BENDIX OFFERS THE CHALK RIVER

KICKSORTER

smallest 100-channel pulse height analyzer available

This is the analyzer recently developed by Atomic Energy of Canada, Ltd. The Cincinnati Division of Bendix Aviation Corporation has been licensed to manufacture and market the analyzer in the United States. Magnetic-core storage is provided for 100 fixed adjacent channels, each having widths from 0.03 to 0.3 volts. With the biased-off window amplifier and a 30-volt spectrum, 1,000-channel analysis can be performed. Average dead-time is 85 microseconds. Design considerations have been discussed in the following references: F. S. Goulding, "KICKSORTER DEVELOPMENTS AT CHALK RIVER" in *Multi-channel Pulse Height Analyzers*, National Research Council, publication 467, pgs. 86-94; F. S. Goulding, "SOME TRANSISTOR CIRCUITS USED IN MAGNETIC CORE TYPE KICKSORTER", 1956 IRE Convention Record, part 9, pgs. 76-81. Cincinnati Division, 3130 Wasson Rd., Cincinnati 8, Ohio.

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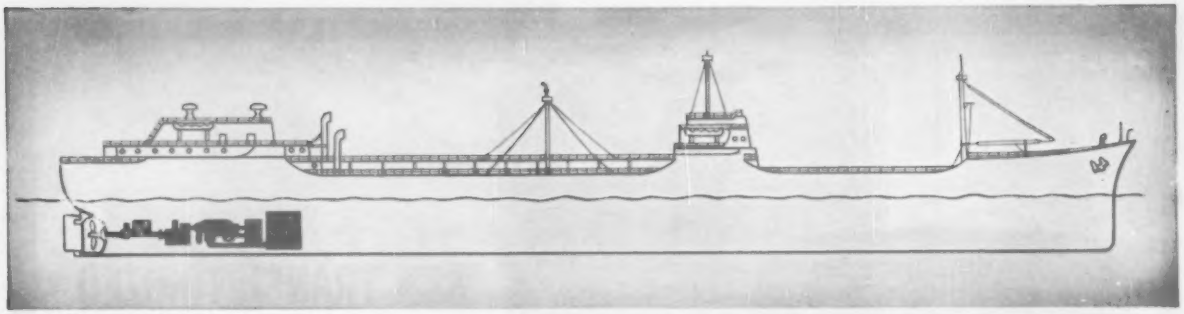


A CCGCR propulsion system as it would appear in a tanker.

PROGRESS REPORT NO. 2

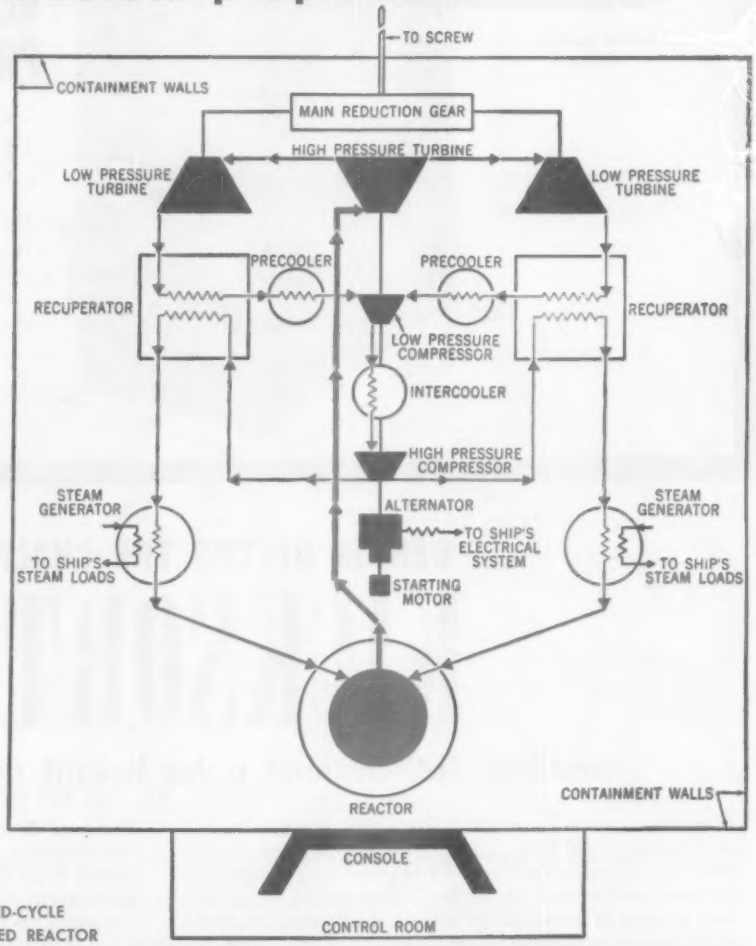
THE CLOSED-CYCLE GAS-COOLED REACTOR
...for nuclear propulsion

Ford Instrument Company is continuing its investigations of the Closed-Cycle Gas-Cooled Reactor, "The Eighth Reactor Type." Latest findings show that the CCGCR has many attractive possibilities for ship propulsion as well as for stationary power plants.

Illustrated on the right is a schematic of a ship propulsion system as visualized by FICo.

There are definite advantages which will make this plant attractive to ship operators. Among these is the drastic reduction of fuel storage facilities. This reduction in fuel carrying requirement can be reflected in additional revenue carrying capacity. In addition, such a system should offer:

- **Low Cost**
- **High Thermal Efficiency**
- **Maximum Safety**
- **A Minimum of Moving Parts**



Simplified Flow Diagram showing major components of ship propulsion system.

THE CLOSED-CYCLE GAS-COOLED REACTOR

REACTOR CONTROL AND INSTRUMENTATION SYSTEMS

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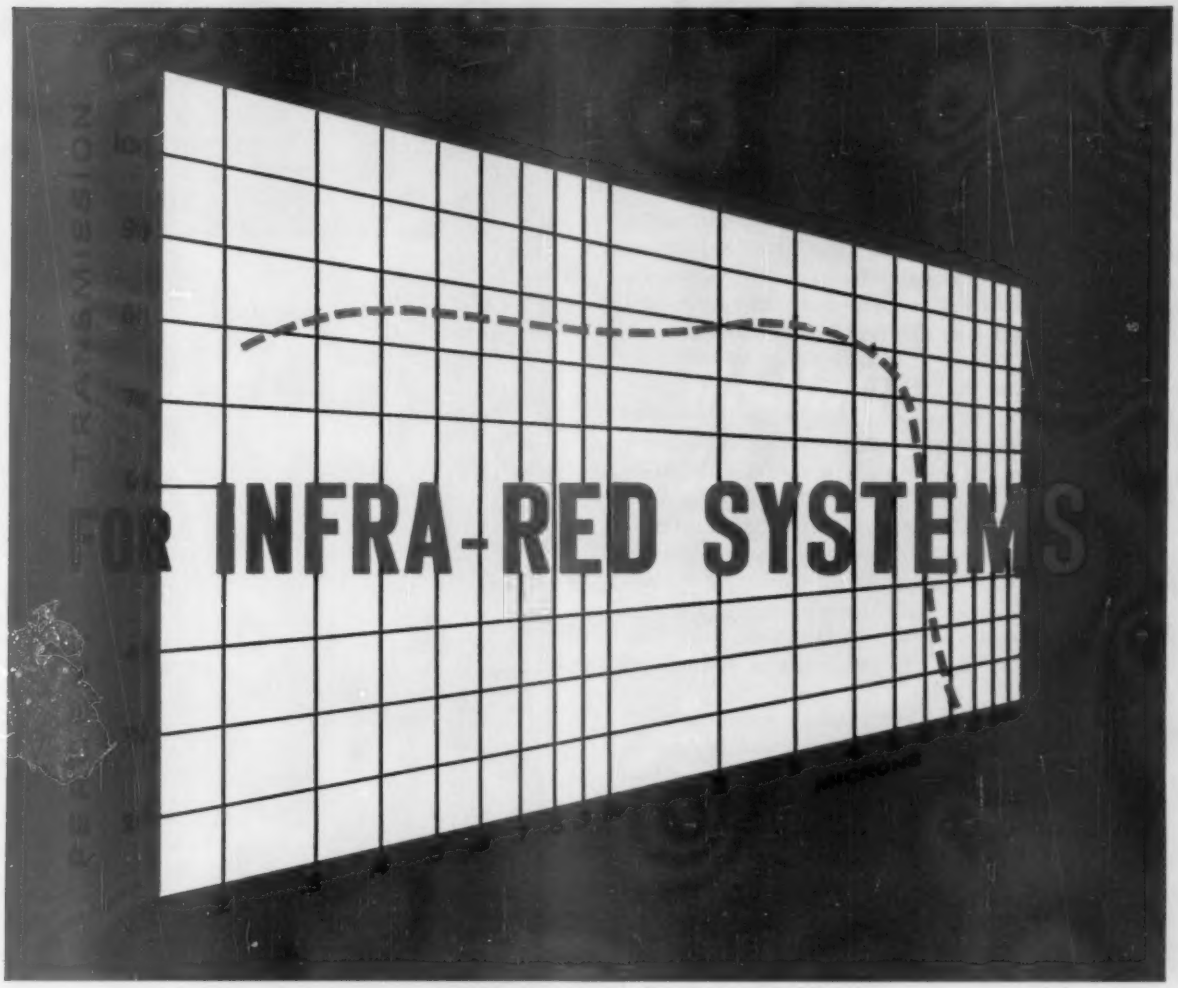

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Recent world events have focussed attention upon the urgent need of the United States for greater development of human resources through education. This country's scientific and industrial supremacy has been seriously challenged. We must tap our mental as well as our material resources to an extent never before attempted if we are to compete with the U.S.S.R.

Aerojet-General Nucleonics is proud of the role in education which it has played in the past; probably more nuclear engineers and scientists have operated the AGN 201 Portable Educational and Research Reactor than any other reactor in existence. Typical of the educational institutions which have recognized America's challenge are these users of AGN 201 reactors: University of California, Catholic University, Colorado State University, U. S. Naval Postgraduate School, Oklahoma State University, University of Utah, University of Akron, and Texas A. & M.

Probably the chief reason for the success of the AGN 201 reactor has been the pioneering approach of Aerojet-General Nucleonics. Appreciating the need for an educational reactor, AGN designed and built the first reactor entirely financed by private capital. Utilizing American mass production techniques for the first time in this field, AGN offered the first commercially available and economical educational reactor. AGN has also offered a reactor training program entirely devoid of security regulations, general enough to give participants an overall perspective of the nuclear reactor field, yet detailed enough to give an intimate knowledge of reactor theory and operation. This program is presented free of charge to educators. Already 180 faculty members of United States and other free world universities have attended this program. Special programs have been presented to representatives of the petroleum and railroad industries.

But significant as these achievements have been, Aerojet-General Nucleonics recognizes the need for maximum utilization of its own resources as one part of the national effort in education which must be forthcoming. We are confident that the United States will meet the challenge. We at Aerojet-General Nucleonics will endeavor to do our part.

AGN reactor systems from milliwatt to multi-megawatt are available. Information will be furnished upon request.

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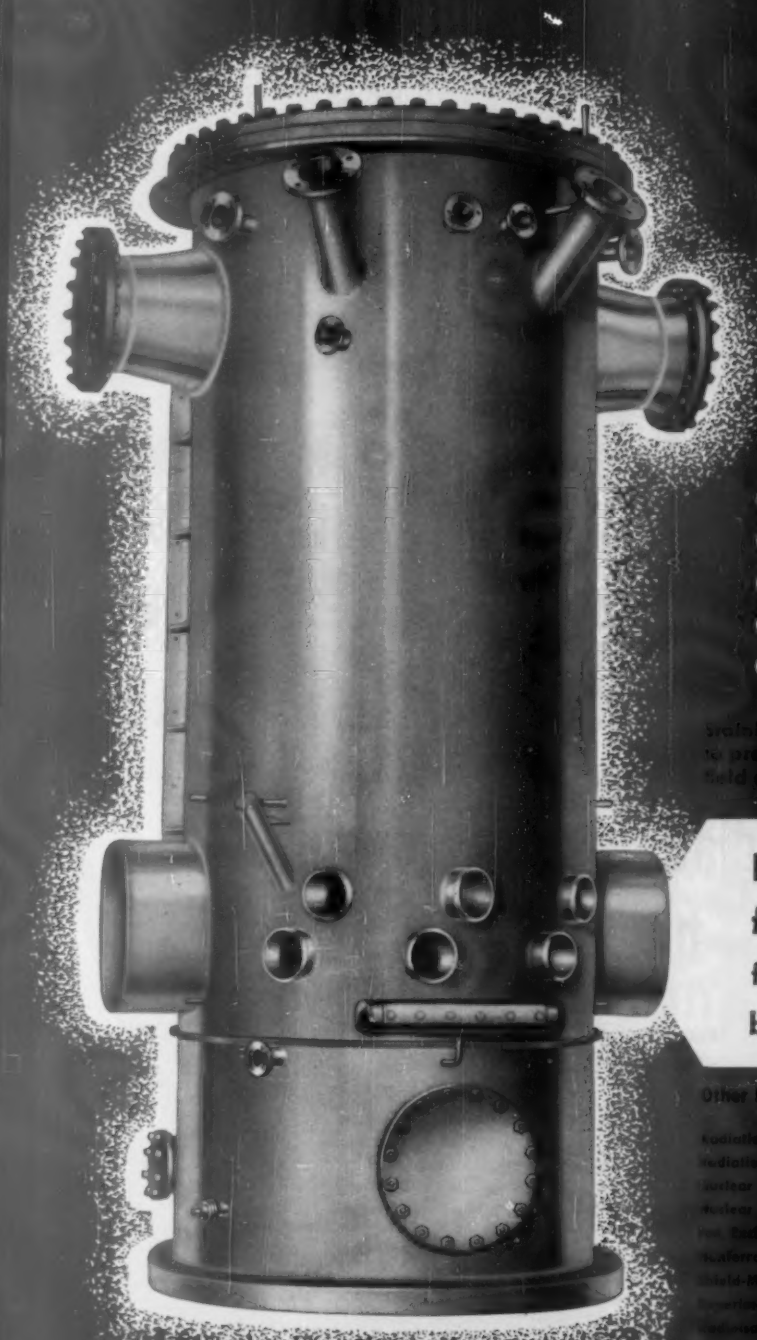

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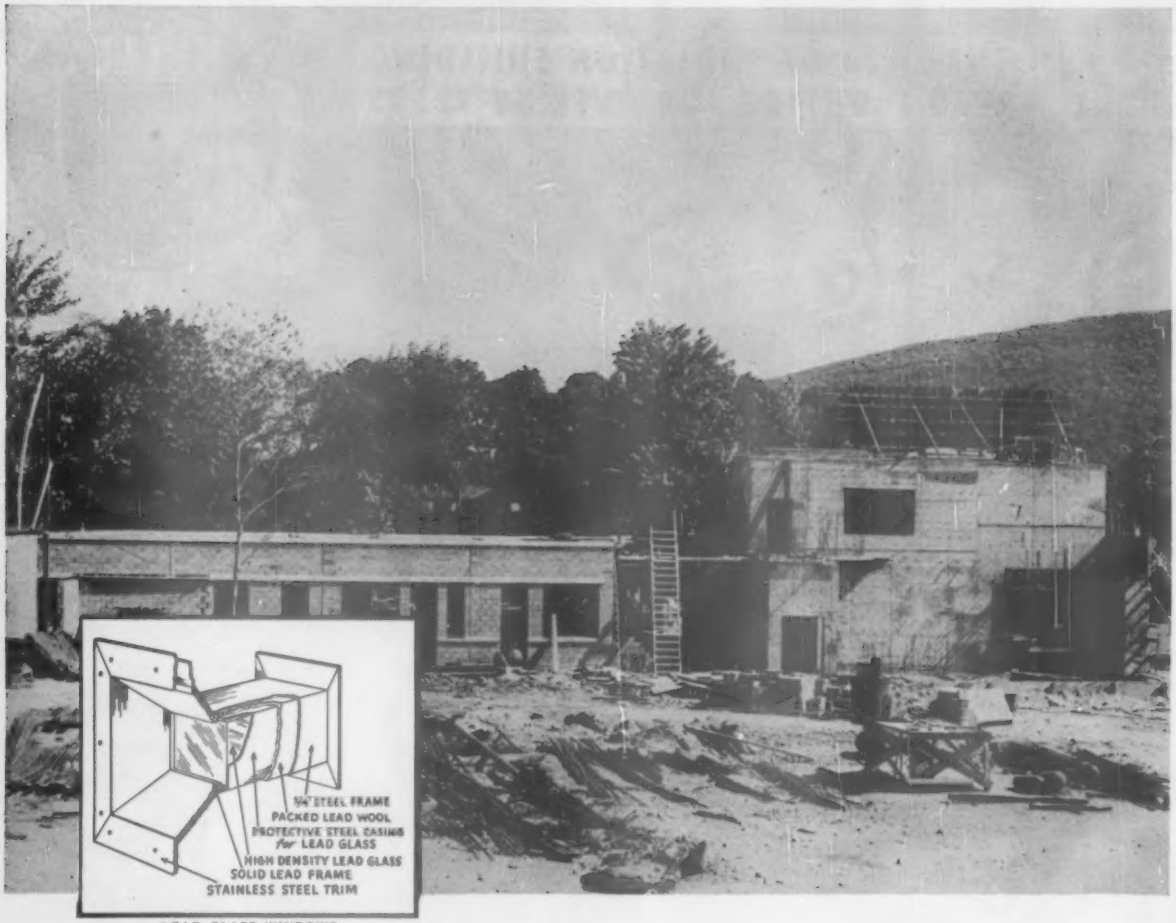

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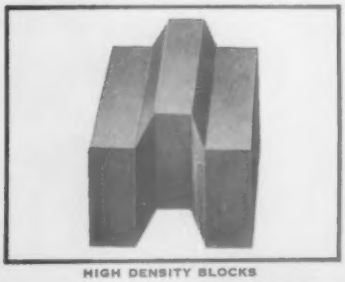

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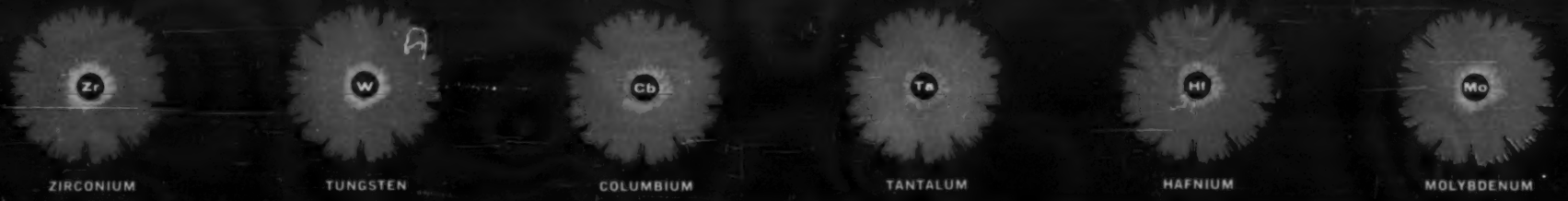

In 1953 Pioneer joined with other groups, all reporting to the Atomic Energy Commission, for constant study of atomic energy application. Today Pioneer is qualified as a consultant to industry in the application of atomic reactor systems to the generation of electric power. Presently, Pioneer is acting as architect-engineer and supervisor of construction of the 66,000 kw commercial atomic power plant shown here. Allis-Chalmers Mfg. Co. is the prime contractor. Scheduled for 1962 completion, the plant, for the Northern States Power Co., will be known as the "Pathfinder".

Organized as Central Utilities Atomic Power Associates, these utilities will share in the research and development costs: Northern States Power Co., Central Electric and Gas Co., Interstate Power Co., Iowa Power and Light Co., Iowa Southern Utilities Co., Madison Gas and Electric Co., Mississippi Valley Public Service Co., Northwestern Public Service Co., Ottertail Power Co., St. Joseph Light and Power Co., Wisconsin Public Service Corp. **PIONEER SERVICE & ENGINEERING CO.**, 231 South La Salle Street, Chicago, Illinois.

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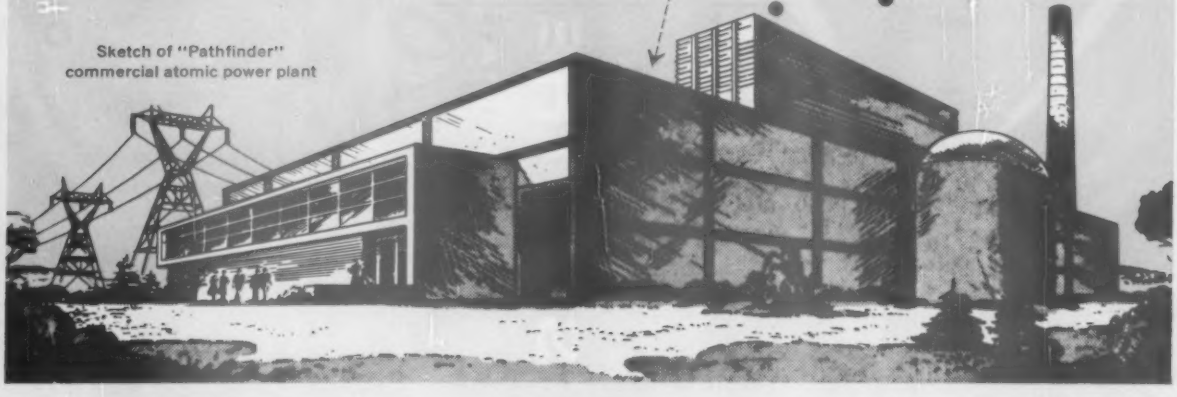
Sketch of "Pathfinder" commercial atomic power plant



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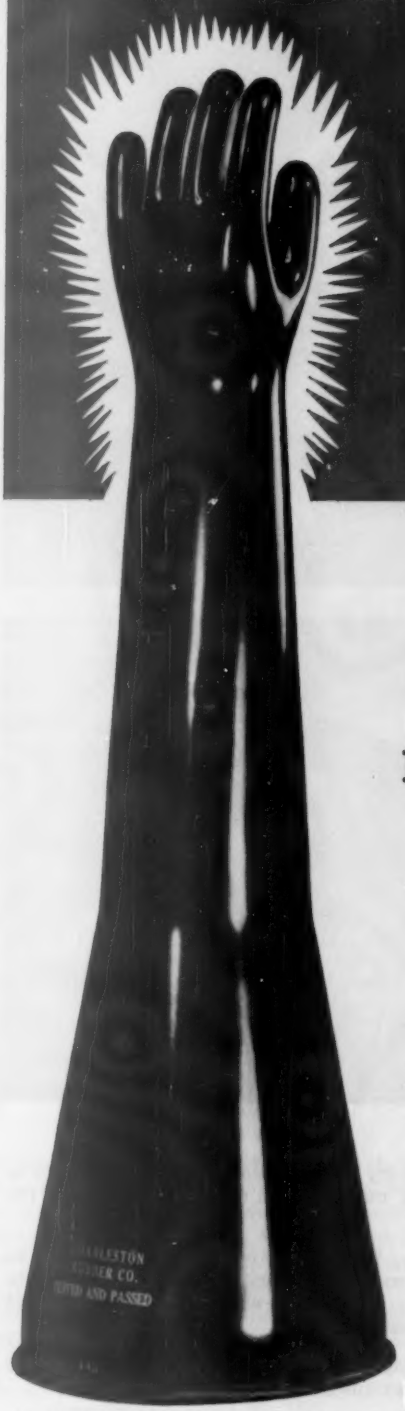

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CHARCO "NEO-SOL" Dry Box Gloves are NOT made by the Neoprene Latex Coagulation Process. They are carefully manufactured of MILLED NEOPRENE by the Multiple-Dip Cement Method, using MOLECULAR solvent solutions of Neoprene. The CHARCO method yields non-porous films of intimate molecular structure with greater homogeneity and impermeability. Our Dry Box Glove Folder graphically illustrates the basic difference, and the superiority of gloves made of multiple-dipped milled neoprene.

CHARCO maintains its own completely equipped and staffed laboratory. We welcome the opportunity to help solve any problems you may have

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CAST nuclear stainless steel valves and fittings now proved economical with superior strength

Cooper Alloy cast nuclear-service stainless steel valves and fittings are saving money, providing greater strength in AEC-contract plants today. Here's the story:

This Cooper Alloy stainless steel fitting for nuclear service, here being machined, possesses a tensile strength of 26,000 psi at 650°F.—20% higher than values specified by code.

Cooper Alloy 16″ stainless steel gate valve body illustrates the wide range of nuclear valves and fittings now being cast by Cooper Alloy for atomic energy service.

YIELD STRENGTHS: CAST vs. FORGED STAINLESS STEEL

Cast Stainless Steel
SA351-CF8 . . . . . 18,400 psi @ 650°F.(1)

Forged Stainless Steel
SA182-F8-304 . . . . . 17,900 psi @ 650°F.(1)

Cooper Alloy Cast Stainless Steel
ASTM351-CF8 . . . . . 22-27,000 psi @ 650°F.(2)

(1) Figures represent minimum yield strengths required by ASME Unfired Pressure Vessel Code, Section VIII, and have been calculated as follows:

$$YS = \frac{\text{allowable stress}}{62.5\%}$$

(2) Figures taken from tests of actual heats of material manufactured by Cooper Alloy for the AEC's SPERT III program at Idaho Falls, Idaho (see Nucleonics, Aug. '57).

Strength: As the figures in the accompanying chart show, Cooper Alloy is currently achieving what many have described as "the impossible": producing 304 ELC stainless cast valves and fittings consistently with yield strengths of 22-27,000 psi at 650°F.! These superior physical properties are finding wide application in meeting the exacting strength and economy demands of the nuclear industry.

How It's Done: These outstanding properties have been achieved by utilizing skills developed through Cooper Alloy's over 35 years of experience in casting stainless steel exclusively. In particular: • Use of proper directional solidification, achieved by proper mold design, plus foundry know-how in metal feeding, ensures a sound solid casting. • An exact balance of chemical composition develops the maximum strength characteristics inherent in the complex structure of stainless steel alloys. • Incorporation of foundry considerations into valve and fitting designs ensures maximization of the alloy's and the part's potential.

Quality Controls: In addition to all usual checks, such as 100% X-ray examination and dye-penetrant surface testing, all components are subjected to a 6,000 psi hydrostatic pressure test.

The Costs: Savings up to 40% have been achieved with sizes of fittings running from 8″—24″.

Want more information? Telephone or write the Nuclear Division, Cooper Alloy Corporation, Hillside, N. J.

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one of a series... ANNOUNCING H&N's NEW NUCLEAR DIVISION

Kelly McBean, Manager of H&N's new Nuclear Division, tells

"What We Learned on Eniwetok About

The Strange Structures that Test Atomic Safety"

"To the eye, this atom age structure is little more than a bleak and faceless building. Yet its seemingly characterless masses of concrete must be meticulously designed. Nine years of continuous experience in the design and construction of the AEC's Eniwetok Proving Ground, plus two years of exhaustive research in the States, has taught us that *nuclear safety requires engineering concepts that are new to industrial design and construction.* Also required is an unprecedented union of specialized science with experienced engineering. Our Nuclear Division offers both, focused on the safety of industrial nuclear facilities in all its aspects, from the nuclear characteristics of the source to the integrity of shielding and containment."

HOLMES & NARVER's long experience with nuclear test facilities has involved massive problems in radiation shielding and blast-resistant construction. Although Eniwetok test data cannot be translated directly into industrial radiation containment concepts, the engineering method can—and the proof of these design methods under maximum radiation and maximum pressure assures more confident safety predictions. But confidence in safe design depends first on sure knowledge of the forces creating the hazard. At Eniwetok, as in your plant, this means the nuclear physicist and the engineer attack the radiation problem together. Our Nuclear Division includes a nuclear physicist who has specialized in reactor hazard evaluation, in all known concepts. The firm invites consultation on special safety problems—or the full responsibility—from plan to finished plant.

A new booklet, "Nuclear Safety," is available upon request

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Whether you are just starting a modest radioisotope laboratory or expanding present facilities, call on Nuclear-Chicago. For complete details on the new Nuclear-Chicago line, write for our new Catalog "Q".

1A Model DS5-3P Scintillation Detector with exposed 2" x 2" sodium iodide crystal and **1B** Model 132 Analyzer Computer for precision gamma-ray measurements using pulse-height discrimination techniques.

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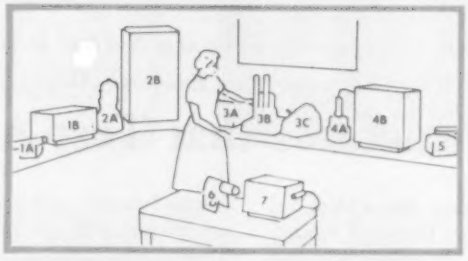
3A Model 183B Count-O-Matic Binary Scaler, **3B** Model C110B Automatic Sample Changer with Model D47 Gas Flow Counter, and **3C** Model C111B Printing Timer for completely automatic changing, counting, and recording of as many as 35 soft beta emitting radioactive samples.



4A Model 3054 Manual Sample Changer with Model DS5 Scintillation Detector which features interchangeable alpha, beta, or gamma sensitive crystals connected to Nuclear-Chicago's finest scaler, the **4B** Model 192A Ultrascaler. Model 192A features decade scale of 10,000, one millivolt sensitivity, and precision automatic circuitry.

5 Model 2612P Portable Survey Meter contains a 1.4 mg/cm² thin window G-M tube for surveying for alpha, beta, or gamma contamination up to 20 milliroentgens per hour.

6 Model 2586 "Cutie Pie" features interchangeable ionization chambers for measuring beta, gamma, or x-radiation up to 250 roentgens per hour.

7 Model 1620A-S Analytical Count Rate Meter offers a wide choice of full scale ranges, four time constants, wide range high voltage supply. It is shown with a Model D34 thin window G-M tube and P11 probe for continuous monitoring or analytical radioactivity determinations.

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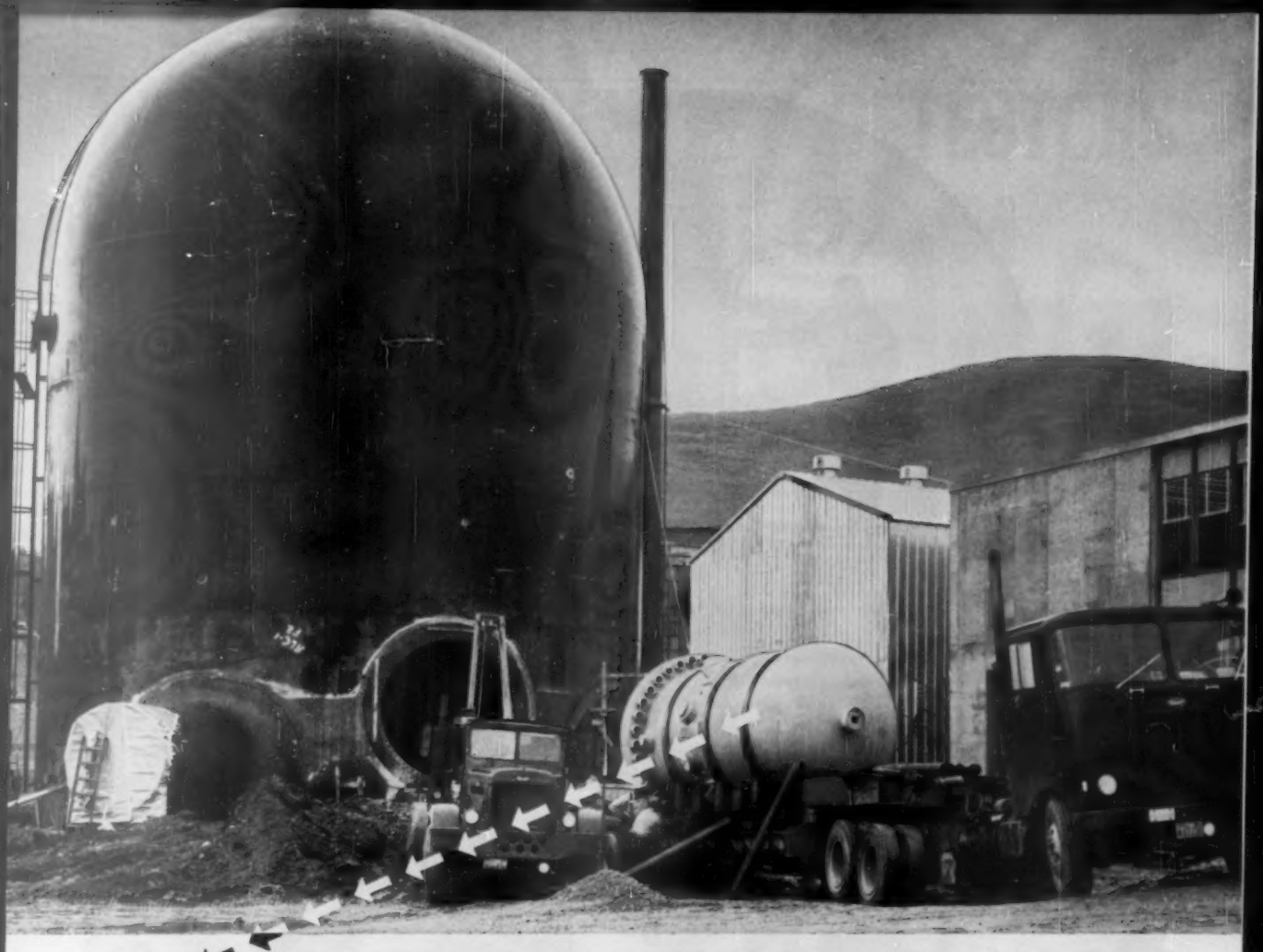

Key vessel for Vallecitos built by Paceco

This 68 ton, 1215 P.S.I. pressure vessel for the developmental boiling water reactor at the General Electric Company's Vallecitos Atomic Laboratory at Pleasanton, Calif. was designed and fabricated by Paceco according to specifications set by the customer.

Paceco is designing and building many pieces of equipment within the new and challenging field of nuclear science. In fact, for the past 10 years, Paceco has designed and built equipment for almost every project of the A.E.C. as well as for the first privately financed pilot plants.

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Consult Paceco for your equipment needs. You will find in many instances that your design and fabrication problems have already been solved by Paceco engineers—that Paceco is ready to go to work for you at a lower cost and with a higher degree of efficiency. If your needs are special, Paceco engineers are available to work closely with you *during the planning stage* as well as the designing and fabrication stages of your equipment.

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Vincent Bicicchi, Pratt Engineer, standing at exterior door of a personnel lock for the Pleasanton, California atomic power plant.

Henry Pratt engineers the...

Door to Atomic Power Plants

The Henry Pratt Personnel Access Lock fulfills one of the most necessary requirements of an atomic power plant. It allows personnel to pass conveniently through the containment vessel to the reactor in such a way that the plant will fully comply with the **AEC code for reactor construction.**

The design emphasizes strength and easy, fool-proof operation. The lock can be built to withstand any practicable pressure, with compression type or pneumatic door seals. Simple operating principles increase its safety factor and include an **interlocking feature** that keeps one door open when the other is closed.

Future Developments in Access Locks now being planned include larger sizes to accommodate trucks, and fully automatic locks that permit manual operation if power fails.

Drawing on a background of 50 years experience in supplying the power industry with valving, steel fabrication and special equipment, **Henry Pratt has been a pioneer in designing and building for atomic power.**

With experience, skilled engineers and two plants equipped with large metal working facilities, you can look to Pratt for help in building tomorrow's power.

See: Nuclear Power Engineering by Henry C. Schwenk, Henry Pratt Company, and Robert H. Shannon, United Engineers & Constructors, Inc. 344 pages, 131 ill., McGraw-Hill; 1957

Personnel Locks already installed . . .

Two locks in the BWR of General Electric's Vallecitos Atomic Laboratory, Pleasanton, Cal.

Two locks in the M.I.T. Research Reactor

Locks now being built . . .

Three locks for the C.N.R.N. Reactor, Ispra, Italy

One lock for the Enrico Fermi Atomic Power Plant of the Detroit Edison Co., Laguna Beach, Mich.

Two locks for the General Electric Test Reactor, Vallecitos, Cal.

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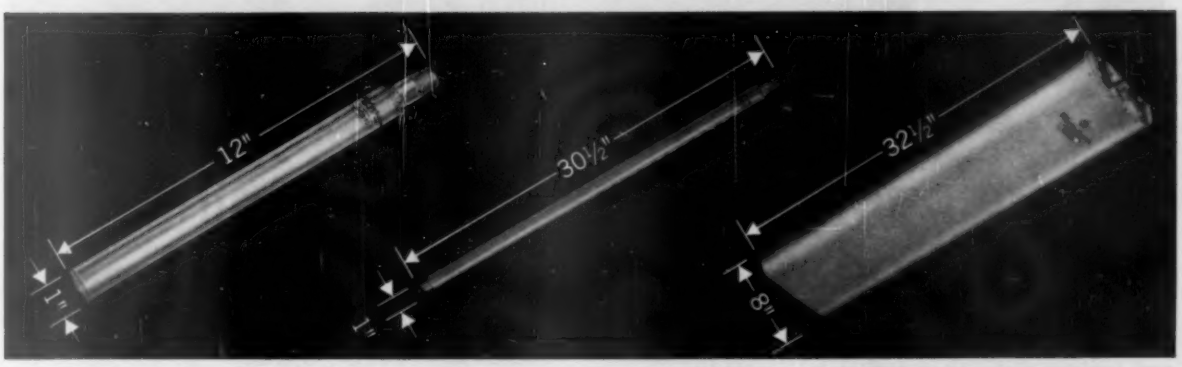
WL-6377 Compensated Ion Chamber: Electrical compensation—guard ring design. All-magnesium construction—B^{10} coated electrodes. Thermal neutron sensitivity: 4.0×10^{-14} amps/nv. Gamma sensitivity: 3.0×10^{-11} amps/R/hour. Operating thermal neutron flux range: 2.5×10^{2} to 2.5×10^{10} nv. Passes Bu Ships 40T9 for vibration and MIL-S-901 for shock.

WL-6376 Dual-Range Fission Chamber: All-aluminum construction—U-235 coated electrodes. *As a pulse counter:* Thermal neutron sensitivity, 0.7 counts/neutron/cm²; Operating neutron flux range, 2.5 to 2.5×10^{5} nv. *As an uncompensated ion chamber:* Thermal neutron sensitivity, 1.4×10^{-13} amps/nv; Gamma sensitivity, 4.2×10^{-11} amps/R/hour; Operating range, 5×10^{5} to 1×10^{10}nv. Passes MIL-STD-167 (Type 1) for vibration and MIL-S-901 for shock.

WL-6327 Uncompensated Ion Chamber: Guard ring design. All-aluminum construction—B^{10} coated electrodes. Thermal neutron sensitivity: 4.4×10^{-14} amps/nv. Gamma sensitivity: 5.0×10^{-11} amps/R/hour. Operating range: 2.5 $\times 10^{4}$ to 2.5×10^{10}nv. Passes MIL-STD-167 (Type 1) for vibration and MIL-S-901 for shock.



WL-6307 BF_3 Proportional Counter: All-aluminum body—enriched BF_3 filled
Thermal neutron sensitivity: 4.5 counts /neutron/cm²
Operating range: 0.25 to 2.5×10^{4} nv
Passes MIL-STD-167 (Type 1) for vibration and MIL-S-901 for shock

WL-6998 BF_3 Proportional Counter: All-aluminum body—enriched BF_3 filled
Thermal neutron sensitivity: 13 counts /neutron/cm³
Operating range: 8×10^{-2} to 8×10^{3} nv
Passes MIL-STD-167 (Type 1) for vibration

WL-6938 High Sensitivity Proportional Counter: Contains four elements similar to WL-6998 in polyethylene moderator. Aluminum body
Thermal and intermediate neutron sensitivity: 45 counts /neutron/cm²
Operating range: 2.2×10^{-2} to 2.2×10^{3} nv

Thanks to its wide experience in Atomic Energy, Westinghouse leads in the Neutron Detector field. Westinghouse makes a complete line of Neutron Detectors for nuclear instrumentation of reactors and critical assemblies. Production quantities are available. For complete technical data, mail the coupon today. *SAMPLE ORDERS INVITED!*

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Inconel guards anodes refining boron-10 in 1400°F bath

Now that boron-10 (extraordinary new neutron shielding material) is commercially available, the story of its production is being told.

The valuable isotope is separated from boron-11 in an AEC-owned plant operated by Hooker Electrochemical Company, designed and built by Singmaster and Breyer.

This part of that story concerns itself with the final refining of boron-10 from potassium fluoborate intermediate.

Hooker does this final refining electrolytically in a modified commercial cell drawing 500 amps at 6v. The cell contains a cylindrical cavity surrounded by graphite anodes. The yield...approximately 200 grams of boron-10...deposits on a central cathode.

1400°F salt bath presents severe design problem

The molten fluoborate is in admixture with fused potassium chloride maintained at a temperature of 1400°F. This posed two design problems.

First, a way had to be found to insure that cathode surfaces would stay smooth and free of pits and hence permit easy removal of the product. This job went to Monel* nickel-copper alloy. Monel alloy resists corrosion by fluorides and chlorides and has suitable conductance.

Secondly, another metal with plenty of resistance to heat, thermal shock, and stress-corrosion was needed to protect the graphite anodes and contain the bath. This job went to Inconel* nickel-chromium alloy.

As you can see above (part on hoist,) a wrought Inconel alloy shell with welded seams is used.

Both Inco Nickel Alloys have performed well in this application . . . outlasted other metals many times over . . . just as they can do for you in similar environments.

For technical assistance with your own corrosion problems, call on Inco's Development and Research Division. Do it any time. *Registered trademark

The International Nickel Company, Inc.

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INCO NICKEL ALLOYS

NUCLEONICS FEBRUARY, 1958

Jerome D. Luntz, *Editor*

Acceleration

IT NOW appears that, except for a very few people, most individuals with a significant interest in the future of the U. S. atomic energy program feel that it must be stepped up in some substantial manner or—in the term that has come into popular usage—it must be accelerated. (See p. 17.)

And, although the long-awaited public statement of U. S. policy objectives in atomic energy has not yet been issued, it is also growing clear that the consensus on this is that a short-term program must be developed that would benefit our foreign friends and that a slightly longer-term effort must now be planned that would bring economically competitive nuclear power to the U. S. in some predetermined period of time. Some attach a very reasonable time scale of five years to the short-term effort and ten years to the longer one.

The difficult chores lie immediately ahead—to devise a sensible program that will serve the policy objectives and then to determine how to implement the program. Although there are wide differences of opinion among reactor specialists as to what kind of a technical program would make the most sense, these differences would probably be narrowed down when a clear-cut time scale is introduced.

Undoubtedly the one technical area in which there already is the most substantial agreement is fuel element technology: the vital need for the development of better fuel elements, particularly for water reactors.

It is equally necessary, however, that many nontechnical uncertainties about the fuel cycle be clarified by some clearcut policy decisions. There are many unanswered questions that must be factored into the thinking of potential customers for power reactors, particularly foreign customers, but also domestic ones. Among other things, there is a need for: a clearcut statement of charges for the preparation, handling and shipping of fuel elements (before and after use); availability of insurance coverage for each of the foregoing; longer assurances on plutonium buy-back guarantees; etc.

BY FAR the knottiest question and the one that will generate the most nonnuclear heat will be the basic one on how whatever program is devised is to be implemented. The several points of view on this range from the belief that any new reactors to be built under an accelerated program should be built by the government under a contract system with AEC calling the shots all the way down the line, to the belief that AEC should supply the money to industry with the latter determining how it should be spent.

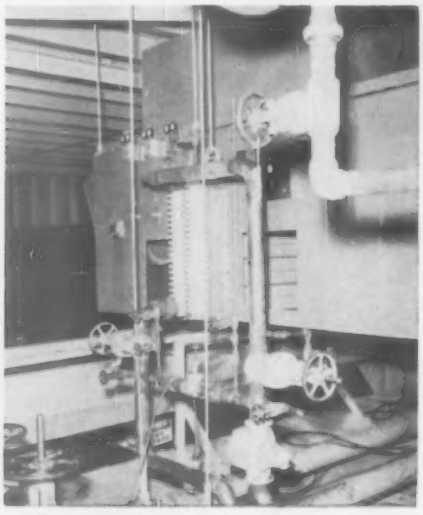
As is generally the case, what is needed is something halfway between the two. The overriding influences on whatever course of action is to be followed are: (1) a specific objective must be achieved, including, in part, the building of certain kinds of reactors, and (2) a strong and efficient nuclear industry must be fostered.

These are not by any means contradictory requirements. The government should devise a plan that will give industry incentive to spend its own money in atomic energy and to work in a cost-reducing manner that will at the same time assure the attainment of established goals.

Considerable sums of money are now going to have to be spent by the government to put the U. S. in a position of unquestioned leadership in atomic energy. Industry recognizes the need for strong governmental support. It is our hope that this support will come and that it will provide the basis for the development of a sound and vigorous U. S. program.

First Use of Reactor Heat for Space Heating . . .

. . . U. K. 1952 World's first nuclear space heat was provided as byproduct by British reactor, BEPO, to adjacent buildings



. . . U. S. 1954 One of 100 air-heating units installed at Hanford in first U. S. byproduct use of nuclear power for space heating

A NUCLEONICS REPORT

The Outlook For

INDUSTRIAL HEAT, as a market for the nuclear industry, has indications of being a sleeping giant. If the utilization of nuclear energy follows the over-all pattern of our national consumption of conventional energy, we may expect that eventually the total energy produced by reactors in the form of heat for industrial purposes will overshadow that produced in the form of electricity. The fact is that of the total energy consumed in the U. S. today over 80% is used directly in the form of heat. Slightly less than 20% is used in the form of electrical energy. Deducting from this tremendous market for heat the large blocks that are used for space heating and transportation, we come to manufacturing, which in the U. S. today consumes substantially more energy in the form of heat than is consumed in the generation of electrical power. Further, this very large market for heat energy is growing at a rapid rate.

Industrial-heat reactors can be conveniently divided into two classes according to their operating temperatures: low-temperature reactors, which produce heat at around 400° F and high-temperature reactors, which operate at temperatures in the vicinity of 1,500° F or higher. The former would be used mostly to supply bulk quantities of low-quality steam for manufacturing processes. The latter would consist of reactors tailor-made for certain specialized chemical and metallurgical operations.

Low-Temperature Reactors

There is in this country a large market for process steam. To name a few of the many products using it: textile fibers, chlorine and alkali, fertilizers from phosphoric acid, petroleum, antibiotics, pulp and paper, alumina and refined corn products. These industries use saturated steam at 50–150-psig pressures for the purpose of driving off water from solutions to produce dry chemicals, or as low-temperature heat added to make a chemical reaction take place at an economical rate. Not only do they have a high utilization factor (90–95%), but load changes take place infrequently and at a slow rate. Regular shutdowns for maintenance are scheduled for present fossil-fueled boilers much in the same way as would be required for reactors.

From the technical point of view it would be quite easy for any one of the half dozen reactor concepts now being pursued to produce steam for these purposes. Such a reactor might be in the 40–60Mw(th) class and would be capable of generating steam in a secondary system at 400° F and 150–250 psi. The secondary system would be required for at least two reasons: (a) In some cases, as much as 50% of the steam generated is consumed in the process so that condensate make-up requirements are quite large and the cost of high-purity water preparation at these make-up rates would be prohibitive; (b) the possibility, however remote, of radioactive contamination in the product precludes the use of steam generated directly in the reactor.

Now, First Reactor for Industrial Heat . . .

. . . Norway 1958 Arrow indicates tunnel entrance to new pressurized-water reactor now under construction inside mountain near Halden, Norway. Reactor heat output will be used to make steam for paper-pulp mill in foreground. Reactor will serve primarily as experimental facility

Industrial Heat Reactors

At present the main doubt confronting low-temperature heat reactors concerns economics rather than engineering. It is not yet clear that reactors can produce steam at the going industrial price. Thus, in designing a heat reactor the nuclear engineer will be primarily concerned with economic rather than technical requirements. His ultimate goal will be to arrive at a reliable design that yields steam for a cost in the vicinity of 65¢/10^6 Btu or lower (see p. 66). To do this it makes sense to take a reactor of proven technical design and concentrate on reducing the capital and fuel costs below their existing levels for electric power plants.

Their proven design and relatively low investment cost make the pressurized-water, boiling-water and, perhaps, the organic-moderated concepts best suited for process-steam reactors. The capital cost of a 135,000-lb/hr process-steam plant (40 Mw) must be kept around $2 million, including the core and the first set of fuel elements, if the economic goal of 65¢/10^6 Btu is to be attained (see p. 69 for a proposed design).

The limited performance demanded of a low temperature industrial-heat reactor will allow many economies in the engineering design.

Thus reactor fuel elements clad in aluminum, rather than stainless steel or zirconium, should be entirely adequate. The pressure vessel, piping, heat exchanger and pumps in the primary loop could be made of carbon steel or one of the low-alloy steels in wide commercial use. In this equipment, cladding of a simple commercially feasible type might be employed for the primary system, but the exotic stainless steels employed in existing reactor types would not be economically feasible. It will also be necessary to make a substantial engineering effort to keep the cost of the containment structure at a minimum, without compromising safety. Instrumentation and controls of a simple and rugged type should be feasible and will be most desirable for low capital cost and minimum maintenance.

In the first few applications, the reactor will probably work in conjunction with two or three fossil-fuel boilers and the reactor operators will be drawn from the same class of personnel as the regular boiler operators. In an all-reactor plant, it would be necessary to have two or three reactors to ensure steam for the plant during routine shutdown for refueling of any one reactor.

Because of the special nature of the problems encountered in shutting down, refueling and restarting a reactor, highly skilled and specially trained personnel will be required for the refueling operation. In the normal process-steam application, these people will only be needed for a few days once or twice a year. Therefore, it will be highly desirable to have this special service furnished by the reactor builder or a special service company set up for this purpose. The reactor owner could be billed on an annual fee basis for this service. *(Continued on next page)*

Many American companies now in the nuclear field are examining the prospects for nuclear industrial heat. But, except for a few paper studies and a modest research and development program being carried out under AEC contract, very little is being done in industry on the development of heat reactors.

This was determined by NUCLEONICS in a survey of engineering and manufacturing concerns.

Most of the companies indicate that they stand ready to adapt their existing designs of electricity-producing nuclear plants to heat production when applications warrant it. Although several companies felt that heat reactors would be competitive before electric power reactors, the general feeling was that the cost reduction necessary for heat reactors will come largely as a result of economies achieved on electricity reactors.

Some concerns have attempted to sell the concept to user industries—in particular to the two in which it is likely to be used first, paper and pulp and the chemical industries.

High-Temperature Reactors

Unlike low-temperature reactors, high temperature heat reactors are still in their technological infancy. There is as yet little evidence that reactors can actually be operated at temperatures in the vicinity of 1,500° F. At the moment, however, the economic incentives for trying to build such reactors appear very strong. Whether or not these incentives are realized will be answered by the future development of high temperature technology.

Possible high-temperature process heat reactor applications can be categorized into three groups:

1. Processes that can make direct application of nuclear heat with little or no change. These would include, for example, the thermal cracking of hydrocarbons and open-hearth manufacture of stainless steel.

2. Processes that will require some modifications in order to utilize nuclear heat. Such modifications may give the resultant process advantages over the existing process. The majority of the possible applications listed in the table fall into this group.

3. Processes that will require complete development. Such processes might be any that produce materials which consume large quantities of energy in manufacture but which are not necessarily produced at high temperatures. The thermal production of magnesium or the distillation purification of sodium are possible examples.

The table lists a number of potential high-temperature-reactor applications. In developing this list no significance was attached to the present or future economic practicality of such reactor applications. The only criterion for inclusion was that the process requires heat at a temperature in excess of 1,500° F.

While one can artificially divide industrial heat reactors into high-temperature and low-temperature types, the practical matter is that every high-temperature reactor concept considered to date produces significant quantities of heat at low temperatures. As one possible high-temperature reactor concept, we can visualize a system in which the fuel elements would be cooled in a conventional (low-temperature) manner but the core arranged to maximize gamma and neutron heating in the reflector and/or moderator. The reflector and moderator would be thermally insulated from the fuel and primary coolant, and cooled by a second coolant. The secondary or reflector coolant would leave the reactor core at high temperatures while the primary or fuel coolant would leave the core at relatively low temperatures.

Such an arrangement might, of necessity, be resorted to where the high-temperature heat would be required in an open cycle system and where the coolant must be uncontaminated by fission products. Preliminary calculations on such a concept indicate that the amount of high-temperature heat generated would be only approximately 10% of the total heat generated. The greatest proportion possible is 14%.

A more refined consideration of possible applications of high-temperature reactors must take into account a number of the rather unique attributes and characteristics of such reactors. For example, at operating temperatures now postulated (>2,500° F) the containment of fission products within a fuel element becomes almost impossible. At these temperatures the volatility of fission products interstitially retained or otherwise absorbed becomes high. Even without cladding failure, diffusion of fission products through the cladding can be expected. Therefore, the coolant in contact with the fuel elements will be as radioactive as the circulating fuel in a homogeneous reactor. This means that the process stream cannot be directly heated with the reactor fuel unless radioactive contamination of the process stream can be tolerated.

The materials problem is by far the most difficult and critical of the problems faced in developing high temperature reactors. At high temperatures, erosion and corrosion of materials are accelerated. Thermal stresses usually exceed the limits of the materials when the mechanical components are designed to withstand operating pressures. In fact, the only consoling feature apparent today is that radiation damage is not significant because, at the temperatures involved, the induced radiation damage stresses are continuously annealed.

* * *

The section on low-temperature heat reactors is based on a paper presented by Edward L. Heller (H. K. Ferguson Co.) at the October 1957 meeting of the Atomic Industrial Forum in New York City. The remainder is from a manuscript by J. F. Kaufman and D. Stewart (U. S. AEC, Washington, D. C.).

Possible Applications for High-Temperature Heat Reactors

Process or product	*Temperature (°F)*
Sintering or casting of metals	3,000–6,000
Nitrogen fixation, Cottrell process	3,700–4,000
Carbides and graphite	3,600–4,000
Fused silicon, fused quartz, etc.	3,100–3,300
Ceramics and refractory brick	3,000
Open-hearth stainless steels	3,000
Glass	2,600
Cement	2,500
Coal gasification	2,500
Copper smelting	2,000–3,000
Wulff process for acetylene	1,800–2,400
Direct reduction of iron ore	1,800–2,500
Cracking of hydrocarbons	1,800–2,200
Lime burning	1,500–2,000
Thermal production of sodium or magnesium	?
Retorting of oil shale	1,300

A NUCLEONICS REPORT

AEC's Industrial-Heat Program

By J. F. KAUFMANN and D. H. STEWART, Jr.,
Division of Reactor Development, U. S. Atomic Energy Commission, Washington, D. C.

AEC's THIRD INVITATION under its power demonstration reactor program provides the possibility of giving process-heat reactors the same support available to reactors used to generate electric power—preconstruction research and development, waiver of fuel use charge and postconstruction research and development.

Apart from this general support, the AEC, in its own research work, has emphasized the development of high- rather than low-temperature process heat reactors. The reason is that, technologically, low-temperature heat reactors can be built today and furthermore experience with electric-power reactors will be directly applicable to low-temperature reactors. On the other hand, development of high-temperature units presents many technological unknowns. Moreover, the cost of developing high-temperature process-heat reactors is very much beyond the means of the likely consuming industries. In most of these industries the heat consumed represents only a small portion of the cost of producing the end product, and the total high-temperature process heat consumed per plant is generally less than 50 Mw. Engaging in a costly reactor-development effort in addition to developing a new chemical process (especially when there is no patent advantage) is hard to justify to a board of directors.

High-Temperature Test Reactor

It is expected that process-heat reactors when built will be designed and engineered for a specific chemical or metallurgical process. Selection of materials of construction, fuel composition, coolant arrangement, etc., will be based upon process parameters, and each process-heat reactor (at least for the first or second generation of reactors) will be a unique machine. As a consequence, the development effort within the AEC is directed toward the general rather than the specific. Emphasis is therefore being placed on the development of a high-temperature test reactor (HTTR) rather than a specific process-heat reactor. A conceptual design study of such a test reactor was made by Nuclear Development Corporation of America for the AEC last year. However, the design limited the test section to a single large helium loop.

As presently visualized, the HTTR will be a more typical engineering test reactor. One possible design consists of four or five loosely coupled two-region cores. Each of these cores in turn consists of an annular fuel array with a center region at high temperature, thermally insulated from the surrounding low-temperature region. Each core is designed to test a specific coolant and its effect on various fuel materials and configurations. The high-temperature coolants receiving consideration at present are all gases and include the noble gases He, A, etc., as well as steam, CO_2 and CO, nitrogen and air. Design of the reactor is being held up until loop experiments demonstrate the practicality of containing and circulating the coolants at the temperatures and pressures of interest.

Coal Gasification

Of the high-temperature coolants, helium has received the closest study to date. Interest in helium arose because of work done by the Bureau of Mines on coal gasification.* The conventional process produces gas by burning coal at high temperature (2,500° F) with relatively pure oxygen in the presence of steam. Based upon coal at $4 and oxygen at $6/ton, the heat used in the process costs about $1.20/10^6$ Btu. Nuclear fuel would cost $0.26 per million Btu (based upon U^{235} at $17/gm).

A nuclear reactor might then provide competitive heat for synthetic fuel production by passing a mixture of steam and powdered coal through a reactor to give "water gas"

$$H_2O + C \rightarrow CO + H_2$$

However, radioactive contamination of the process gas and the possible poisoning of the reactor by sulfur and other deleterious components of coal require the use of an intermediate heat-transfer fluid in a closed-cycle system.

A cooperative work-and-study program between the Bureau of Mines and the AEC was started more than a year ago with emphasis being placed upon the development of a high-temperature helium test loop. As an initial step a small loop was constructed at the Morgantown Experiment Station. This is being followed by a larger loop that will continuously circulate helium under 2,000 psi pressure through an induction heater. In the heater the helium temperature will be raised to approximately 2500° F. From there it will flow to a heat exchanger where it will give up its heat to air. The cooled helium (1500° F) will then be returned by a circulating blower to the induction heater.

The mere assembly and successful operation of the test loop will represent a significant accomplishment. Each component of the loop, from the piping to the measuring instruments, is a development item never built before.

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*Bureau of Mines Report R-1 4564 (1949).

A NUCLEONICS REPORT

The Market for Heat Reactors

By KARL M. MAYER *Nuclear Products—Erco Division of ACF Industries, Inc., Washington, D. C.*

A RECENT MARKET ANALYSIS of the heat consumed in the 460 industries recognized by the Census Bureau led to these conclusions about the potential industrial heat market in the United States:

- Based on estimates of future growth of the gross national product, the total consumption of industrial heat is expected to rise from 10×10^{15} Btu to about 14×10^{15} Btu per year between 1957 and 1967.
- During the same period at least 10.4×10^{14} Btu/year additional capacity will be added in the form of steam units that generate heat at a cost of more than 60¢/10^6 Btu. In nuclear terms this would be equivalent to building seventy 100 Mw(th) reactors each year (assuming the reactors operate at a 50% plant factor).
- Industrial heat equipment sales during this period will include a relatively large number of units (see Fig. 1) with capacities around 250,000 pounds of steam per hour [80 Mw(th)] and with operating steam pressures below 250 psi serving manufacturing centers mostly in the northeastern United States.
- There is a definite market in the low-temperature industrial heat field for a 40–60 Mw reactor that takes less than two years to build and can supply heat at 65¢/10^6 Btu [equivalent to about an 8-mills/kwh(e) power cost for an electric power reactor].

Heat Costs

The table gives the yearly consumption for seven industries that use a total of 89% of the industrial heat consumed in the U. S. In the long run, nuclear heat will become competitive with fossil fuels in most of these industries for the same reasons that nuclear electric power will eventually become competitive.

An effort was made in the market study to estimate the amount of heat produced in the U. S. at various cost levels. Calculations were made of the total cost of steam generated by each of 1376 new boilers. A plant operating and investment cost of 25¢/10^6 Btu and the average 1954 fuel price for the state involved were assumed for each unit. The results are shown by the diagonal-line bars in Fig. 2.

If we take the value predicted above for the total new plant capacity that will be built during the next ten years and assume that it will have this same cost distribution, then we arrive at a projected market for each cost level in the period 1957–1967. This market is indicated by the gray bars in Fig. 2.

The projected market calculated in this way will be conservative as far as nuclear sales are concerned for a number of reasons. First of all only new capacity is represented—replacement units have not been included. Also not taken into account is any possible rise in conventional fuel costs over the next ten years. If individual plant fuel cost data had been used instead of state averages, the distribution in Fig. 2 would have been more spread out. (The dotted bars in Fig. 2 show the cost distribution expected for individual plant data.)

Nonpower Heat Consumed*

Industry	*10^9 Btu*	*% of total*
Primary metals	2,962,581	32.8
Petroleum and coal	1,843,078	20.5
Chemical and allied	958,772	10.6
Stone, clay & glass	839,996	9.3
Food & kindred prod.	689,377	7.7
Paper & allied prod.	493,909	5.5
Machinery	232,903	2.6
Total (above)	8,020,616	89.0
National total (1954)	9,009,179	100.0

* By seven largest users in 1954.

Nevertheless even this overly conservative picture of the market predicts that there will be some demand for heat units operating above 70¢/10^6 Btu and a substantial demand in the 60–70¢/10^6 Btu range. There is a hope that moderate-size [40–100 Mw(th)] "economy" versions of present-day reactors could compete at these cost levels (see p. 69).

What Size Heat Units?

Granted a large potential market exists for industrial heat units operating at a cost that might be met by heat reactors in the 60 Mw(th)-size class, there is still the question whether industry can use units as large as this. Again we turn to a survey of existing units to provide clues for future demand. An analysis of the sizes of 11,841 boilers sold in the United States between 1945 and 1957 to (a) manufacturing industries, (b) utilities and (c) all others (hospitals, schools, etc.) is summarized in Fig. 1.

Most of the boilers sold to the manufacturing industries are indeed, "small" by utility standards—more than half of the industrial boilers have a continuous steam capacity of less than 40,000 lb/hr [~10 Mw(th)].

On the other hand, during the period of the study, manufacturing industries bought over 1,000 units with steam capacities of 100,000–500,000 lb/hr (~30–170 Mw(th)). Moreover the trend for the future will definitely be in the direction of larger rather than smaller units.

Economic Problems

The economic opportunity for industrial heat reactors can be summed up by the observation that there appears to be a not insignificant market in this country open to anyone who can build

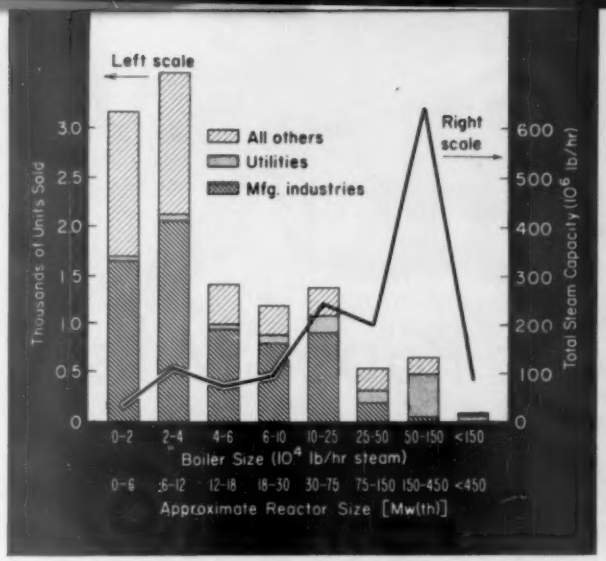

FIG. 1. Distribution in size of 11,841 boilers sold in U. S. between 1945 and 1957. Equivalent reactor sizes are given at top of figure. Although most units sold are small in size, substantial number are in size range (30 Mw and up) of interest tc reactor builders now looking at possibilities of industrial heat

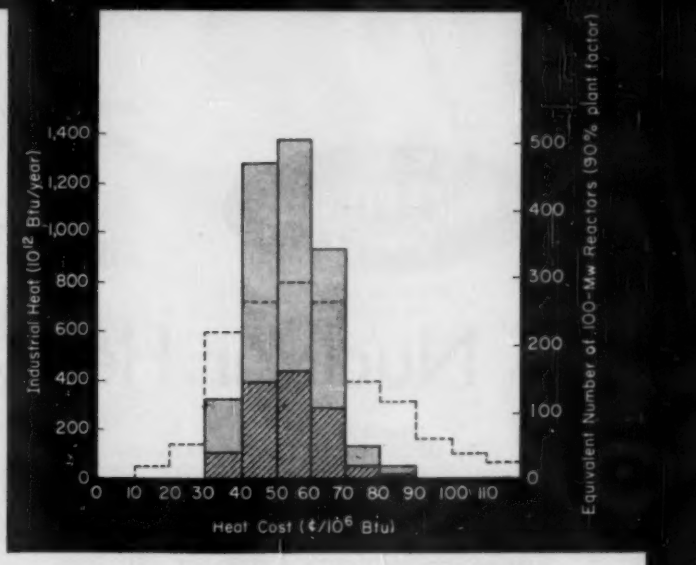

FIG. 2. Lined bars show distribution of heat cost for 1,376 existing boilers. Based on this distribution, gray bars show estimated market for new capacity each year for next ten years. Dashed bars show market potential if actual rather than state average fuel cost data had been used

reactors in sizes below 100 Mw(th) that can produce steam at about 65¢/10^6 Btu. Why, then, have reactor builders so far failed to get beyond the pencil design stage in this potentially lucrative field? One reason is that building a reactor to produce 65¢ steam is not going to be easy to do. This cost level is equivalent to a power cost for a reactor producing electricity (at 25% efficiency) of roughly 8 mills/kwh(e)—about the same as the cost of conventional electric power.

In reaching this goal, the industrial heat reactor is handicaped compared with a utility reactor because of its small size. On the other hand, unlike the utility reactor which must strain temperature and pressure limits to get the 25% efficiency quoted above, the heat reactor can enjoy the economic advantages of more relaxed steam conditions.

The fact is, however, that no reactor has yet been put together in the U. S. that delivers any kind of steam for a cost as low as 65¢/10^6 Btu. Although there is definite hope that this can be done (see p. 69) potential investors will be hard to convince until there has been an actual demonstration. Still, this does not explain why reactor companies have chosen to be so predominately active in the utility field where, at first glance, the chances for profit are not that much larger. One answer is that the basic nature of the industrial heat market makes it more difficult for reactor builders, first, to locate profitable applications and, then, to sell the idea to the potential industrial user.

The industrial heat market is much more complex than the power market from the viewpoint of the economic analyst. The "end product" of the power industry is uniform; the ratio of heat input to product output is more easily studied; the ratios of heat cost to value of product made are well known; the number of plants in the industry is relatively small; the production process is relatively uniform; the capital structure is relatively uniform throughout the industry, etc.

Census statistics have shown us that a nation-wide heat-reactor market can be anticipated. It is a different story to try and locate the individual manufacturing plants that can use these reactors. Even using the census data merely to decide on a list of "most likely" or "most unlikely" industries turns out to be a hopeless task. A long list of possible criteria can be made to judge the relative likelihood of various industries. Besides the ones already mentioned these might include such things as the fraction of product cost attributable to process heat, the plant requirements for both power and non-power heat, and so on.

Although one can conceivably rank all 460 industries according to each of a number of valid criteria, it is impossible to incorporate all this into a final selection because the relative importance of the various criteria are not known. This complexity of the industrial heat market has certainly tended to discourage people from looking at the heat field (in as much detail as the power field) as a potential market for nuclear energy.

Much more intensive market research remains to be done. A major share of this task might well take the form of cooperative studies between potential buyers and sellers of nuclear heating equipment.

The fact that the field is made up of a great number of small users in highly diversified activities creates other problems* as well. Long-term financing, prevalent in the utility business, is not found in many industries likely to use process-heat reactors. In chemical industries, for example, a 30% return on invested capital is generally desired. Few industrial companies make plans for plants that take more than two years to build. Finally, companies tend to be frightened away by present safety, insurance, and operating requirements. Thus, it seems† the risk for the construction of the first plant will fall squarely on the reactor designer and manufacturer, unless he can develop some workable method of sharing it with the AEC. The risk, involved, however, is limited to $1–2-million, well below that for a large electric utility plant. If the manufacturer is successful, he has immediately available a very substantial market for identical reactors in the U. S.

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* Suggested by D. Stewart and J. Kaufmann, AEC, Washington, D. C.

† Edward L. Heller, Meeting of the Atomic Industrial Forum, Paper No. 57-AIF-4 (1957).

A NUCLEONICS REPORT

Nuclear Heat for Paper Mills?

By GEORGE PERAZICH* *The National Planning Association, Washington, D. C.*

THE PAPER and pulp industry would appear to be a likely customer for nuclear process steam. A first look shows that the heat needs in this industry might well be satisfied by the use of heat reactors. The over-all demands for heat energy in this area are already large (about $180-million in 1956) and are becoming rapidly larger. Not only is there a trend to the use of heat units in the reactor-size range but the units are operated at a high load factor and are being located more and more in remote regions where the price of conventional fuel is high.

Heat Consumption

Pulp, paper and paper-board mills consume about 80% of the total energy used by the paper industry. In 1956 U. S. pulp mills used about 170×10^{12} Btu for process heat at a cost of $55 million. This comes to roughly 8 lb of coal or 100,000 Btu of heat for each dollar's worth of pulp output. For the same year the fabrication of pulp into paper and paper board used up 310×10^{12} Btu of process steam at a cost of $100 million to produce a $4-billion gross product. (Roughly ⅔ of this heat is used for drying the sheets as they leave the paper making machines.) This amounts to 80,000 Btu per dollar's worth of paper. In addition considerable sums were spent for electric power.

Unit Size

The average pulp and paper mill requires a heat unit of less than 20 Mw(th). But there are many mills, including some located in high-fuel-cost regions, that use heat-generating units several times larger. We have estimated that each of the five largest pulp mills consumed an average of nearly 3×10^{12} Btu of process heat in 1954. If they operated at 90% capacity (a realistic figure for this industry), each could use a reactor of about 100-Mw(th) capacity. Where power must be locally generated, perhaps as much as 5×10^{12} Btu of energy could be used by each of these mills. Similarly the eighteen largest paper and paper board mills could also use heat-generating units of about 90 Mw(th).

Heat Costs

The price paid by individual mills for conventional fuel varies strongly with geographical location. According to census estimates, the average price paid by pulp and paper mills in 1956 for commercial fuels was close to $32¢/10^6$ Btu. This price, however, is lower for mills in the south that burn natural gas and oil; it is much higher for mills in the New England and Great Lakes regions that use high cost coal. We estimate that in 1956 the *average* fuel cost to New England pulp and paper mill operators was close to $50¢/10^6$ Btu, and to those located in Wisconsin, Michigan and other Great Lakes regions about $40¢/10^6$ Btu. Given these averages, then, depending on location and on the type of transportation facilities available, some mills must pay as high as $75¢/10^6$ Btu.

A figure for the total cost of process heat in this industry can be had by adding to the fuel costs estimated charges for operation and return on investment. We can assume an operating charge of 0.6 mills/kwh(th). A steam boiler of 100,000 kw(th) capacity can be installed for $25/kw(th) which, using a plant factor of 90% and an annual charge of 15%, gives a fixed investment cost of 0.5 mills/kwh(th). Since a fuel cost of $30¢/10^6$ Btu corresponds to 1 mill/kw(th), then a unit burning fuel at this price would have a total heat cost of about 2 mills/kwh(th); at $60¢/10^6$ Btu the cost would be 3 mills/kwh(th) and so forth.

To get an idea at what fuel-cost level nuclear reactors could compete let us assume the same operating cost for the nuclear plant and arbitrarily set the nuclear fuel cost at 0.7 mills/kwh(th).* For a $30¢/10^6$ Btu fuel cost, then, nuclear heat could compete if the nuclear plant could be built for $40/kw(th); at $60¢/10^6$ Btu the investment could be as high as $90/kw(th). These costs are very nearly in range with those of electric power reactors operating today. For instance, EBWR is now operating at 50 Mw(th) and cost $4.6 million which gives a unit investment of $92/kw(th).

Potential Market

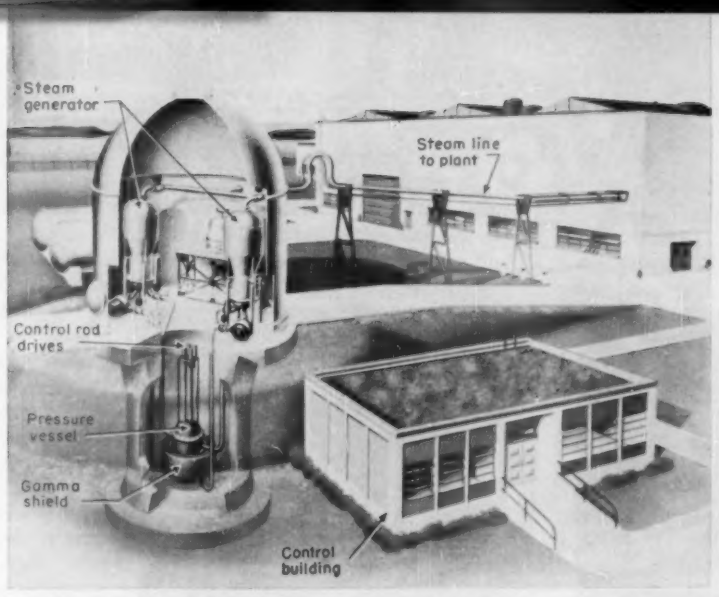
The high rate of expansion of the pulp and paper industry is especially encouraging for nuclear energy. Between 1947 and 1954 the value of pulp and paper (including paper board) outputs in the U. S. increased 60% and 69% respectively. This corresponds to an annual *increase* in energy consumption of 24×10^{12} Btu which in turn is equivalent to the energy output of eight 100-Mw(th) reactors. Of course not all of this increased capacity is built in the form of large units or in high-fuel-cost regions. However the trend in the industry is distinctly in both of these directions. Conventional heating units of reactor size are becoming increasingly more popular. Like other extractive industries, the paper and pulp mills are being forced to more remote locations for raw materials as the more convenient sources become depleted.

* * *

Based in part on a forthcoming report, "Nuclear Process Heat in Industry" by The National Planning Association, Washington, D. C.

* PRESENT ADDRESS: Galaxy Inc., Washington, D. C.

* This would correspond to 2.8–3.5 mills/kwh(e) for a nuclear electric plant.



CONCEPTUAL NUCLEAR STEAM plant produces industrial steam at competitive cost

ESTIMATED CAPITAL COSTS

Item	*Cost (10^3)*
Reactor, shield and insulation	79
First core and blanket	193
Steam generators and pressurizer	197
Pumps and valves	146
Instruments and control drives	131
Water-treatment system	42
Miscellaneous equipment	63
Containment	150
Control building	20
Construction labor	170
Site development	84
Engineering & overhead	200
Undistributed	293
Total	$1,768 = $44/kw(th)

A Low-Cost Heat Reactor

THE HEAT REACTOR shown in the artist's conception above is an all-purpose low-pressure steam-generating unit designed to be competitive with conventional units operating at fuel costs of 65¢/10^6 Btu or higher.* A pressurized-water reactor, it produces 135,000 lb/hr of 150-psig saturated steam (about 40 Mw reactor heat output). The reactor core uses 10 kg of fully enriched U^{235} and would last about 6 months with a 30% burnup. A blanket with 1.7 tons of natural UO_2 is proposed, having a life of about 5,000 Mwd/ton With aluminum or possibly aluminum-nickel alloy cladding, a water temperature of 450° F in the primary loop can be maintained without danger of excessive corrosion. Economy is attained by producing 1–1.25 times as much heat in the blanket as is produced in the fuel elements.

To minimize cost, carbon steel and aluminum are used extensively as structural materials, stainless steel is used as little as possible. The fuel elements are the aluminum-clad MTR type; the blanket is formed of aluminum tubes containing UO_2 pellets. Standard components and off-the-shelf items such as pumps, valves, steam generators, and pressurizers, are specified where their reliability is a proven fact and their cost moderate.

The reactor vessel is made of carbon steel, internally clad with stainless steel, and measuring 4.5 ft i.d. by 11.5 ft high. Control-rod drives are mounted on the removable, bolted, flanged head.

To provide safe operating conditions during the replacement of fuel or blanket elements, the reactor will be located in a concrete pit under 20 ft of water.

Plant Operation

Operation of the plant will be fully automatic. The reactor control will be a semistandard unit, actuated by primary-water temperature in normal operation. Water temperature will be set to control the reactivity level, which in turn will actuate the control rods to hold the power level of the reactor at the required point. For startup, the operator would push the start button to actuate the equipment. Retraction of the control rods that start the reactor, would be under automatic control to hold the rate of change of reactivity within safe limits until the steam flow is up to the required rate. For normal shutdown, or a reduction of load, the reactor would automatically respond to the change in load or shut the reactor down as required. Should an emergency exist, a "scram" button will produce instant shutdown.

Heat Costs

The operating costs for the 135,000-lb/hr unit are estimated to be 30.6¢/10^6 Btu for fuel and 21.2¢/10^6 Btu for labor, depreciation and miscellaneous expenses. This comes to 51.8¢/10^6 Btu, less a Pu credit of 7.1¢/10^6 Btu, giving a net operating cost of 44.7¢/10^6 Btu (100% load factor). On a cost-of steam basis, this is competitive with about $10 coal at 90% load factor and 8¢ oil. There is not too much change for other loads. However, the capital cost of the nuclear unit is higher than the comparable sizes of fossil fuel generators. A breakdown on this figure is given in the table.

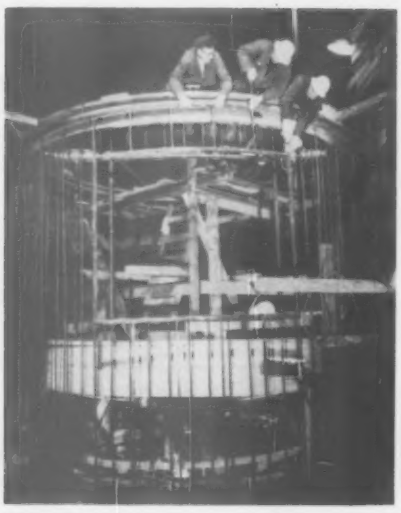
If we assume that a 135,000-lb/hr coal-burning unit costs $1,200,000, the extra capital cost of the nuclear plant would be $568,000. The savings in operating cost of the nuclear plant against 65¢ steam is $155,600/yr without Pu credit or $240,100 with Pu credit. That would pay off the additional capital cost in 3.6 yr without Pu credit or 2.36 yr with it. That is an exceptionally good return for this type of capital investment.

* * *

This article is based in part on a paper presented by Edward L. Heller and Deane O. Hubbard at the annual meeting of the American Institute of Chemical Engineers (1957).

* Designed by Bell Nucleonics division, Bell Aircraft Corp., Buffalo, N. Y. The division has since been disbanded.

A NUCLEONICS REPORT



CONSTRUCTION PROGRESS on Norway's heat reactor is documented by views before and after pouring of concrete shield. Additional protection was afforded by building reactor inside of mountain near city of Halden. Norwegian concerns have all major work contracts

Heat Reactor Prospects Abroad

If heat reactors look promising for the U. S., they look even more promising for foreign countries. Fuel prices are generally higher (sometimes by a factor of two or three) than prices on the U. S. east coast. In addition, a given reactor plant can usually be built and financed in a foreign country at a smaller investment charge (for instance, capital costs are about 50% higher in the U. S. than they are in England). It seems likely, therefore, that foreign countries (probably in western Europe) will be the world's first proving ground for practical heat reactors.

Norway

Norway's Halden reactor (see figures above and NU, Jan. '58, 21), when it goes critical this year, will be the world's first reactor to use its heat output to supply steam for an industrial plant. The 20-Mw(th) boiling-water unit will deliver 482° F 588-psi steam to a nearby paper and pulp plant. The primary function of the reactor, however, will be to serve as an experimental facility (among other things the Norwegians plan to use it to develop a ship-propulsion reactor). Thus nuclear steam will supplied on an intermittent basis depending on the experimental program. Operating under these conditions Halden will not be able to pay its way as a steam reactor; however, there will be a chance to collect cost data and operating experience.

Sweden

Sweden is looking forward to the construction of a reactor that will supply space heating for the city of Västerås. The 100-Mw(th) reactor will deliver 120° C steam to an existing central-heating network in parallel with conventional boilers operated by the State Power Board. This agency will build and operate the reactor and sell the nuclear heat to the city. By the early 1960's it is expected that the reactor will furnish half of Västerås' central heat. With a construction cost of $10 million and 10% annual capital charge, the nuclear steam will be competitive with ordinary steam; if the charge were 15% the nuclear steam could not compete.

The Västerås reactor (see figure and table of characteristics) will be a pressurized-water type using D_2O in the primary system and H_2O in the secondary. Design parameters are listed in the table. A temperature difference of 30–35° F between the heavy water and light water is taken in order to save heavy water in the heat exchangers.

With so moderate a coolant temperature as 140° C it is not necessary to provide for a heavy-water pressure of more than about 8 atm. With such a low pressure it is possible to have a pressure vessel with a very moderate wall thickness. Consequently, the best design is not to use special pressure tubes as in the high-pressure power

reactor* but a pressure vessel. The water enters the reactor vessel from above, moves down and enters the tubes around the fuel elements in their lower ends, moves upwards in these tubes and collects in a special pressure vessel at the top of the reactor vessel and goes from there to the heat exchanger. The tubes are made so that they can be easily exchanged from above.

The simplest design would be to use a reflector of heavy water about 35 cm thick. However, as this would be comparatively expensive, the design shown has a graphite reflector inside the pressure vessel. The core with the moderator of heavy water is included in an aluminium vessel. The moderator and reflector spaces are at same pressure. In reality the CO_2 gas which is used to cool the reflector graphite keeps the pressure above the water in the expansion vessel.

Fabrication of components will start this year with some parts already on order at Allmanna Svenska Elektriska Aktiebolaget. Startup is scheduled for the end of 1960. Besides this one, ASEA is looking at plans for two more heat reactors.

* R. Liljeblad, NUCLEONICS **15**, No. 11, 165 (1957).

Britain

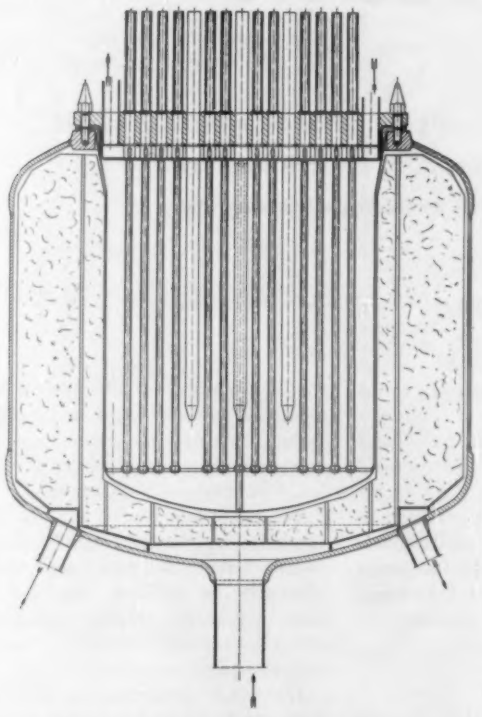
On the other side of the picture, the British, who have a vigorous nuclear electric program, have shown little interest to date in nuclear industrial heat. According to the Ministry of Power, no British industry or firm is "actively" considering this application of nuclear energy. Major industrial heat consumers, such as Imperial Chemical Industries, have uniformly limited themselves to preliminary studies. The Central Electricity Authority, which operates the British power reactors, says that it has no plans for using heat from its plants, even as a by-product. The Atomic Energy Authority admits to having no program for heat reactors. The general feeling of the British is that the capital investment for heat reactors of useful size would be too high.

A good reason for British attitude is that, at the moment, British experience is limited to gas-cooled, graphite designs. These reactors, compared with water reactors, are more expensive to build and, therefore, less suited to heat-reactor applications.

* * *

The Swedish reactor description was based on material from Ragnar Liljeblad, A. S. E. A., Västerås, Sweden.

Engineering Design Information for Sweden's Space-Heat Reactor



LAYOUT of D_2O core and graphite reflector

Total heat power	100	Mw
UO_2	8.6	tons
D_2O in the reactor	20	"
D_2O total	26	"
Reflector graphite	56	"
Fuel elements		
Number	234	
Number of bars in one element	7	
Diameter of the bars	15.8	mm
Al canning	1	"
Length of bars	2,600	"
Specific heat power		
Average value, total	12	kw/kg
Average, central element	19.5	"
Heat load at canning surface		
Average value, total	39	w/cm²
Average, central element	63	"
Maximum, central element	82	"
Maximum can temperature	152	°C
Cooling system		
Quantity of D_2O circulating	364	kg/s
Water velocity (central element)	3.5	m/sec
Number of separate circuits	4	
Operations pressure	12	bar
Pressure drops		
In heat exchanger	1.9	bar
In pipes	0.8	"
In reactor	0.8	"
Total	3.5	"
Temperatures		
Incoming D_2O	140	°C
Outgoing D_2O	75	"
Incoming H_2O	60	"
Outgoing H_2O	120	"
Circulation pumps		
Capacity per pump	0.090	m³/s
Pumping power, total	170	kw

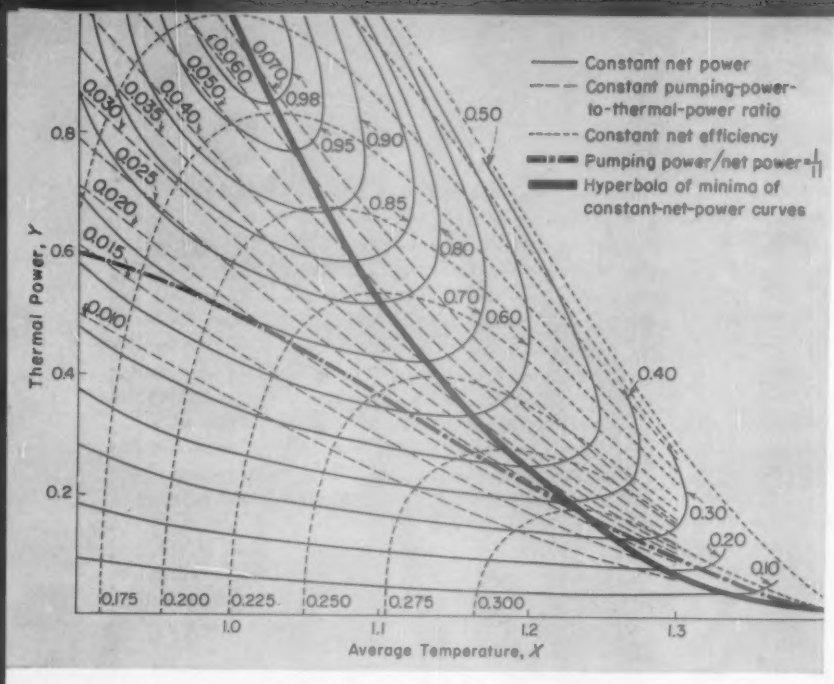


FIG. 1. Lines of constant net power, constant pumping-to-thermal power ratio, and constant net efficiency have this form on an average-temperature-thermal-power plane

Thermodynamics of Gas-Cooled Reactors

With a few simplifying assumptions one can make a general analysis of reactor thermal properties. The resulting equations show the influences of basic parameters on total system performance

By GILBERT B. MELESE* *Commissariat à l'Énergie Atomique, Centre d'Études Nucléaires, Saclay, France*

THERMODYNAMIC ANALYSIS in terms of simplified basic equations permits the reactor designer to make a useful initial choice of his design parameters. From this he can proceed to detailed engineering with necessary compromises.

A straightforward approach is to write the fluid-mechanics and heat-transfer equations for the central channel of the reactor. This is done in terms of a flux form factor, assuming a cosine distribution along the channel length. Then one can extend the analysis to the whole reactor in terms of a radial form factor.

The resulting expression for output electrical power can be written as a product of five factors. Each factor displays the influence on the output of one of the following sets of variables: (1) outside variables, (2) nuclear quantities, (3) maximum can temperature, (4) dimensions and gas pressure, (5) properties of the coolant gas.

Method of Approach

Let us consider the over-all efficiency of a thermal heterogeneous nuclear reactor fueled with natural uranium and cooled by a pressurized gas. Assume that the energy-recovery system consists of a heat exchanger and a steam cycle. This does not include the case of a gas turbine, but this type of study could be extended to that case.

The moderator can be either a solid (graphite or beryllium) or a liquid (heavy water); the technology would obviously be different but not the basic equations. Slight enrichment of the fuel or other variations (*1*) would lead to similar conclusions.

We will seek to simplify the equations governing such a reactor so as to obtain simple relations among the net electrical output and the main variables. These simplified equations will

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permit determination of the optimal characteristics of such a reactor with a good approximation.

Fuel-Channel Equations

It is useful to study the most highly rated or "central" channel before extending the analysis to the whole reactor. The heat-transport equation reads (for symbols see table at right)

$$P_{tc} = q_c C_{avg}(\theta_o - \theta_i) \qquad (1)$$

The equation for heat transfer per unit length from the fuel element to the coolant can be written

$$(1 - \epsilon)P_{tc}\phi(x)/l = h[t(x) - \theta(x)]S_e \qquad (2)$$

h is the average of the heat-transfer coefficient taken around the can in a given cross section. It can be written in terms of the average Margoulis (or Stanton) number M as $h = MqC_{avg}/A$.

S_e, which appears in Eq. 2, is defined so as to take care of possible extended surfaces with efficiencies smaller than one. It is a function of both geometry and mass flow.

One can derive a simple relation between the temperature rise of the gas in the channel and the difference between the maximum can temperature and average gas temperature

$$\frac{\theta_o - \theta_i}{t_{max} - \theta_{avg}} = 2 \sin\beta \sin\frac{\pi l}{2L} \qquad (3)$$

with

$$\tan\beta = \frac{M}{2\gamma(1-\epsilon)} l \frac{S_e}{A} \frac{1}{\sin(\pi l/2L)} \qquad (4)$$

For a cosine flux distribution one finds

$$\gamma = \frac{\pi l}{2L} \frac{1}{\sin(\pi l/2L)} \qquad (5)$$

Just for the sake of simpler formulas, the extrapolated length will be taken equal to the actual length. Equations (4) and (5) will then read

$$\frac{\theta_o - \theta_i}{t_{max} - \theta_{avg}} = 2 \sin\beta \qquad (4')$$

$$\tan\beta = \frac{M}{\pi} l \frac{S_e}{A} \qquad (6)$$

In order to have a safety margin, we neglect the factor $1/(1 - \epsilon)$, the value of which is of the order of 1.07.

The heat-conduction equation inside the fuel rod gives an upper bound to the difference between maximum fuel temperature and maximum can temperature. (Recognize that these two maxima do not occur in the same cross section.)

$$T_{max} - t_{max} \leq (1 - \epsilon)\frac{P_{tc}}{l}\left[\frac{B}{8\lambda} + \frac{1}{2d_o h_f}\right] \qquad (7)$$

(The temperature drop in the can itself is assumed to be negligible.)

B is a function of the ratio of external to internal diameters of the fuel rods. It depends on the type of cooling. For external cooling of a cylindrical rod one obtains

$$B = 1 - \frac{2\log(d_o/d_i)}{(d_o/d_i)^2 - 1} \qquad (8)$$

For a full rod, B is equal to one.

When both maximum fuel temperature and maximum can temperature

Symbols Used in This Article

A	Cross sectional area of coolant channel
b	Pitch of the uranium lattice
B	External-internal-diameter function (see Eq. 8)
C_c	Coolant specific heat at constant pressure and temperture θ_c
C_{avg}	Average along the channel of the coolant specific heat at constant pressure
D	Core diameter
d_o	Outside diameter of fuel
d_i	Inside diameter of fuel
E	Aerothermodynamic coefficient (Eq. 20)
f	Average value of the total friction factor in the channel
F	Radial form factor—ratio of average flux to maximum flux
h	Average heat transfer coefficient
h_f	Heat transfer coefficient fuel to can
K	Ratio of total pressure drop to fuel-channel pressure drop
l	Total length of fuel elements in a channel
L	Extrapolated length (to zero flux)
M	Average value of the Margoulis (or Stanton) number
N	Total number of channels
p	Ratio of average pressure to atmospheric pressure
Δp	Pressure drop in a channel
P_t	Thermal power for a channel
P_e	Net electrical power for a channel
P_p	Pumping power for a channel
q	Coolant mass flow (in a channel)
S_e	Effective heat-transfer perimeter of fuel element
S_w	Fluid-friction (or "wet") perimeter of channel
$t(x)$	Can surface temperature as a function of x
T_u	Uranium temperature
U	$(\theta_o/t_{max})^{1/2}$ (see Eq. 21)
W	Nondimensional pumping power
x	Length coordinate along a fuel channel
X	Nondimensional average temperature
Y	Nondimensional thermal power
Z	Nondimensional net electrical power
β	Angle corresponding to the maximum can temperature (see Eq. 5)
γ	Longitudinal form factor—ratio of maximum flux to average flux
ϵ	Fraction of fission heat generated in moderator
λ	Thermal conductivity of uranium
η_a	"Mechanical" efficiency of steam cycle (see Eq. 11)
η_b	Blower efficiency
η_t	Thermal efficiency of the steam cycle
η_T	Net electrical efficiency
ρ	Coolant density
ρ_a	Coolant density at atmospheric pressure and at temperature θ_a
ρ_e	Gas density at entrance to blower
ρ_{avg}	Average density of coolant in the channel
$\theta(x)$	Coolant temperature along channel
θ_a	Fictitious sink temperature (see Eq. 11)
θ_{avg}	$= (\theta_i + \theta_o)/2$, average coolant temperature in a channel
θ_i	Inlet coolant temperature
θ_o	Outlet coolant temperature
$\phi(x)$	Neutron flux from factor ($\phi_{max} = 1$)

Indices

avg	Averages (taken either along channel or around can)
max	Maxima
c	Central-channel values
T	Whole-reactor values
′	Values at optimal point.

are limited, and when the thermal power is also given, Eq. 7 permits one to find the geometry of the rod. (One must always remember to check the result against nuclear considerations.)

The pressure drop in the fuel channel for turbulent flow is given by the relation

$$\Delta p_c = \frac{f}{2}\frac{q_c^2}{\rho_{avg}}\frac{lS_w}{A^3} \tag{9}$$

The parameter f is designed to include the effects of density change due to temperature rise.

For small pressure ratio the power required to circulate the gas through the channel and also the external pipes and heat exchangers can be written

$$P_{pc} = \frac{k}{\eta_b}\frac{q_c}{\rho_c}\Delta p_c \tag{10}$$

For a great number of classical steam cycles the thermal efficiency can be written in the simple form

$$\eta_t = \eta_a(1 - \theta_a/\theta_{avg}) \tag{11}$$

Here η_a is a kind of mechanical efficiency ($\sim$0.75) and θ_a a fictitious sink temperature ($\sim$330° K).

Assume the gas is circulating in a closed cycle through the fuel channel, the heat exchanger and the blower. Since the heat produced by compression in the blower flows into the coolant gas, the net electrical power produced by the channel will be

$$P_{ec} = \eta_t(P_{tc} + P_{pc}) - P_{pc} \tag{12}$$

By combining Eqs. 1, 4, 9, 10 and 11, Eq. 12 can be written

$$P_{ec}/P_{tc} = \eta_a\left(1 - \frac{\theta_a}{\theta_{avg}}\right) - Q\frac{P_c^2}{(t_{max} - \theta_{avg})^3} \tag{13}$$

with the coefficient

$$Q = \frac{K}{16\eta_b}\cdot\frac{1}{C_{avg}^3\rho_c\rho_{avg}}\frac{f}{\sin^3\beta}\left(\frac{lS_w}{A^3}\right)\left\{1 - \eta_a\left(1 - \frac{\theta_a}{\theta_{avg}}\right)\right\} \tag{14}$$

For the sake of simplicity the four quantities M, f, S_c and β are assumed to be independent of the thermodynamic variables P_t and θ_{avg}. In fact they vary slowly with Reynolds and Prandtl numbers and also with the ratio of can and coolant thermal conductivities.

With the help of Eq. 6 the coefficient Q can be written with sufficient accuracy for gas coolants

$$Q = \left(\frac{\pi^3 K}{16\eta_b}\right)\left(\frac{1}{C_a^3\rho_a^2 p^3}\right)\left(\frac{1}{l^3}\frac{fS_w}{(MS_c\cos\beta)^3}\right) \tag{15}$$

Notice that this coefficient (which is in first approximation independent of the variables P_t and θ_{avg}), is the product of three factors. The first one depends only on the external parameters, the second one on coolant properties, and the third one on the aerothermodynamical properties of the fuel channel.

Optimal Characteristics

For a given maximum can temperature, the net electrical power P_{ec} is a function of the two thermodynamic variables P_{tc} and θ_{avg}.

The maximum value of P_{ec} is easily deduced from Eq. 13 by partial differentiation. The values corresponding to this maximum are

$$\theta'_{avg} = (\theta_a t_{max})^{1/2} \tag{16}$$

$$\eta'_T = P'_{ec}/P'_{tc} = \tfrac{2}{3}\eta_a[1 - (\theta_a/t_{max})^{1/2}] \tag{17}$$

$$P'_{ec} = \frac{2\cdot 3^{1/2}}{9A^{1/2}}\left\{(\eta_a t_{max})^{1/2}\left[1 - \left(\frac{\theta_a}{t_{max}}\right)^{1/2}\right]\right\}^3 \tag{18}$$

(From these one can deduce P'_{tc}.)

Notice that *the optimal average gas temperature is the geometrical mean of the maximum can temperature and the fictitious sink temperature* and that the corresponding net efficiency depends only on these two temperatures and on the "mechanical" efficiency η_a. One can find in these conditions that *the value of the pumping power would be half that of the net electrical power.*

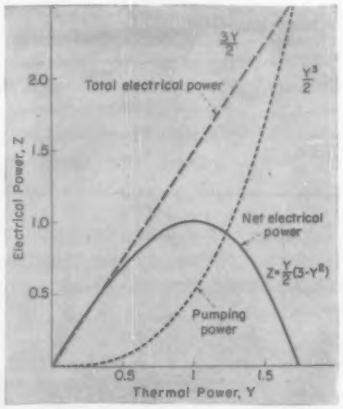

FIG. 2. For constant coolant temperature, required pumping power increases faster than total electrical power. Thus net power goes through a maximum

Equation 18 can be written again with the help of Eq. 15

$$P'_{ec} = \frac{8\cdot 3^{1/2}}{9\pi}\left(\frac{\eta_b}{\pi K}\right)^{1/2}(p\rho_a C_a^{3/2})\, lE\{(\eta_a t_{max})^{1/2}[1 - (\theta_a/t_{max})^{1/2}]\}^3 \tag{19}$$

The aerothermodynamic factor E is defined by

$$E^3 = \frac{(MS_c\cos\beta)^3}{fS_w} = \frac{(\pi A\sin\beta)^3}{fS_w l^3} \tag{20}$$

($MS_c l = \pi A\tan\beta$ by Eq. 6.)

Obviously one will not operate the reactor at the optimal point defined by Eqs. 16–20 since the pumping power would be much too large and the net efficiency much too low. But we shall use the coordinates of this point as optimal coordinates with which to define nondimensional characteristics of the reactor fuel channel. If the parameters η_a, θ_a and t_{max} are supposed to be fixed, the scale of power will be determined uniquely by the factor P'_{ec} (η'_T being also fixed). We can then compare coolants and geometries.

Let us define the nondimensional variables

$$X = \theta_{avg}/\theta'_{avg};\ Y = P_{tc}/P'_{tc};\ Z = P_{ec}/P'_{ec}$$

With these variables Eq. 13 reads

$$Z = \frac{Y}{2}\left[3\frac{1 - U/X}{1 - U} - Y^2\left(\frac{1 - U}{1 - UX}\right)^3\right] \tag{21}$$

where $U = (\theta_a/t_{max})^{1/2}$.

The corresponding equation for the nondimensional pumping power W can be written

$$W = \left(Y\frac{1 - U}{1 - UX}\right)^3 \tag{22}$$

By definition, the coordinates of the optimal point are $X = Y = Z = 1$; let us now explore the rest of X, Y, Z space. Consider first in the X,Y plane the lines of constant Z, or nondimensional net electrical power (Fig. 1).

The points of contact of their horizontal tangents lie on the hyperbola

$$Y = \frac{1}{X}\left(\frac{1 - UX}{1 - U}\right)^2 \tag{23}$$

For a given value of the thermal power Y this curve defines the temperature X that gives maximum Z.

One can also draw the lines of constant values of the net electrical efficiency, $\eta_T = P_{eo}/P_{to}$. Equations are

$$Y^2 = \left(\frac{1 - UX}{1 - U}\right)^3 \left[3\,\frac{1 - U/X}{1 - U} - 2\left(\frac{\eta_T}{\eta'_T}\right)\right] \quad (24)$$

with the value $\eta'_T = \frac{3}{8}\eta_o(1 - U)$ (see Eq. 17).

Their maximum values lie on the same hyperbola (Eq. 23). They cut the X axis at right angles. They are tangent to the X axis at the points $X = 1/U$ (the hyperbola is also tangent at the same point).

One can finally draw the lines of equal value of the ratio of pumping power to thermal power

$$Y^2 = \frac{2}{\eta'_T}\left(\frac{P_{po}}{P_{to}}\right)\left(\frac{1 - UX}{1 - U}\right)^3 \quad (25)$$

Figure 1 shows the diagram with the lines of constant values of Z, η_T and P_p/P_t.

Figure 2 shows the type of variation of the net electrical power with thermal power for a given average gas temperature. For Z maximum the value of the pumping power is half that of the net electrical power.

By dividing the pumping power by a factor 8 (that is, by dividing the thermal power by 2), the value of the net electrical power is decreased only by ~45%. (These results are independent of the value chosen for the temperature). The maximum values of Z (for a constant value of the average temperature) correspond to the points with vertical tangents on the lines of constant values of Z.

The equation of the corresponding curve given by $Z = W$ (see Eqs. 21 and 22) reads

$$Y = \frac{(1 - U/X)^{1/2}(1 - UX)^{3/2}}{(1 - U)^2} \quad (26)$$

Then the following equation

$$Y = \frac{1}{2}\,\frac{(1 - U/X)^{1/2}(1 - UX)^{3/2}}{(1 - U)^2} \quad (26')$$

defines the points for which the pumping power is $\frac{1}{11}$ of the net electrical power. It corresponds to the points we just considered above in Fig. 2 when we divided the thermal power by 2. In practical designs of power reactors one will keep fairly close to this curve (26′) when the temperatures are imposed, and close to the hyperbola (23) when the thermal power is given.

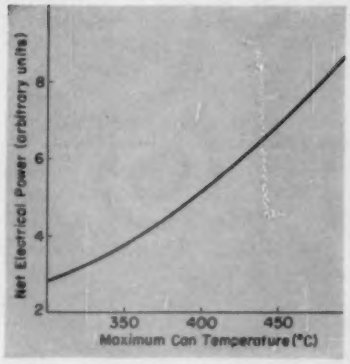

FIG. 3. Net electrical power as a function of maximum can temperature

Whole-Reactor Analysis

In general there is a large variation of heat release between the central channel and the external channels. Since the heat output is usually limited by the maximum flux, it is desirable to reduce the ratio of maximum flux to average flux to increase output.

A uniform outlet-temperature distribution can be obtained by orificing the coolant, either by using entry or exit orifices or by decreasing the size of the fuel channels from the center to the outside of the core.

It is obvious that by having the same coolant flow through all reactor channels, one needs a much greater pumping power and gets a much lower exit temperature than with orificing.

One can also use fuel rods of different geometries at various distances from the center in order to increase the reactivity and also flatten heat flux.

For power reactors one should flatten neutron flux and control temperatures by regulating coolant flow. In these calculations the gas is assumed to enter all channels at the same pressure and temperature. The exit pressures are also assumed to have the same value for all channels, and orificing is used to adjust flow. We will limit consideration to identical fuel rods and channels just for simplicity. If the flow is controlled in such a way as to obtain a constant exit temperature, the maximum can temperature will be the same in each channel by Eqs. 4 and 6. If one allows for a variation of β with the power (or with the mass flow), the maximum can temperature will slightly decrease in the external channels.

With the help of Eqs. 1, 10 and 13 the net electrical efficiency and the ratio of pumping power to thermal power can be seen to be the same for every channel. Total thermal power can be written $P_T = NFP_{to}$.

The net electrical output of the reactor will be $P_{eT} = NFP_{eo}$. Thus the maximum output is $P'_{eT} = NFP'_{eo}$.

By Eq. 19, this maximum value of the net electrical power is

$$P'_{eT} = \frac{8 \cdot 3^{1/2}}{36} F \left(\frac{\eta_b}{\pi K}\right)^{1/2} l \left(\frac{D}{b}\right)^2 (p\rho_a C_a^{3/2}) E \left\{(\eta_b t_{max})^{1/2}\left[1 - \left(\frac{\theta_a}{t_{max}}\right)^{1/2}\right]\right\}^2 \quad (27)$$

In the case we are considering, the diagram of Fig. 1 is still valid for the whole reactor; one only has to multiply the values of the various powers by the factor NF. The net efficiency of the whole reactor is seen to increase if the reactor is divided into several regions. The temperature should be different in each region. It should increase as the heat output decreases.*

The nondimensional diagram of Fig. 1 permits comparing the respective operating points of various reactors of the same type for the same maximum can temperature. For a dual-purpose reactor like Calder Hall, it would be convenient to place the operating point next to the hyperbola of our diagram with a fairly high value of the nondimensional thermal power. (One finds $Y = \sim 0.7$.) But for a reactor primarily designed for power one should try to get a better net electrical efficiency without too much pumping power. The operating point should therefore be approximately between the hyperbola and the curve of Eq. 26′ for which $P_p/P_e = \frac{1}{11}$ and also below the curve $Y = 0.5$ (which means a relatively small nondimensional thermal power).

Net Output

Equation 27 shows the influence of parameters of various types. It can be written

$$P'_{eT} = \frac{8 \cdot 3^{1/2}}{36}\left(\frac{\eta_b \eta_o}{\pi K}\right)^{1/2}\left(\frac{F}{b^2}\right) (t_{max}^{1/2} - \theta_a^{1/2})^2 (plD^2)(\rho_a C_a^{3/2}) \frac{(MS_a \cos\beta)^{3/2}}{(fS_w)^{1/2}} \quad (28)$$

* In the G2 dual-purpose reactor at Marcoule, France, there are two zones of entrance temperature and two different zones of exit temperature.

◆ The first factor $(\eta_b\eta_a/\pi K)^{1/2}$ is concerned with the *outside* of the reactor. The efficiency of the blower and that of the steam cycle should obviously be as good as possible and the external pressure drop (K), reasonably low.

◆ The second factor (F/b^2) is *nuclear:* the neutron flux should be as flat as possible—large value of F—and the lattice pitch should not be too large. Notice that this pitch is mainly determined by nuclear considerations. It is a function of the moderator and of the size of the uranium rod, for instance. Owing to mechanical considerations (fabrication, loading, unloading) it can not be taken too small. Besides, reactor physics requires a minimum size for criticality in actual operating conditions, and extra reactivity must be allowed in order to use a uranium alloy for better irradiation properties. This extra reactivity permits adding extended surfaces, flattening the flux, etc.

◆ The third factor $(t_{max}^{1/2} - \theta_a^{1/2})^3$ shows the importance of the *maximum can temperature;* this temperature is determined both by mechanical and corrosion properties of the canning material. An increase of this temperature from 400° to 450° C permits an increase of power of approximately 40% (see Fig. 3). However, an increase in temperature must be compatible with the reactions among coolant, uranium, graphite, steel, etc. One should not forget to check that the maximum permissible temperature of the uranium is not reached (see Eq. 7). Usually this temperature is determined by the alpha-beta phase transition.

◆ The fourth factor (plD^2) is a function of both the *dimensions* of the reactor and the *coolant-gas pressure.* When there is a pressure vessel (with a graphite moderator for instance), the maximum thickness of the vessel and the maximum allowable stress give an upper bound for the product of the vessel diameter and the pressure. In practice, this limit is often determined by welding problems. An increase in core diameter brings an increase in power due both to a larger plant size and to the possibility of using the excess reactivity to get a flatter flux. An increase in gas pressure brings an increase in net power and a decrease in pumping power. Since the pressure × vessel-diameter product is limited, one should reach a compromise between these two.

One can also use the excess reactivity given by an increase in core diameter to use larger fuel-channel diameters; in this case an increase in gas pressure becomes less important. In heavy-water-moderated reactors, one can either have a pressure tank or else have pressure held by the channel tubes themselves. In the latter case, the channel diameter (and not the core diameter) is limited by the value of the pressure.

The length of uranium in the channel must not be too large for pressure-drop or metallurgical considerations.

◆ The fifth factor $(\rho_a C_a^{3/2})$ shows the influence of the choice of *coolant gas.* Equation 28 shows the maximum net power to be proportional to this coefficient. The following table shows relative values of this factor.*

Gas	$(\rho_a C_a^{3/2})_{rel}$
N_2	0.62
Air	0.645
CO_2	0.765
He	1.0
H_2	2.3

◆ The last factor is the *aerothermodynamic* coefficient E (see Eqs. 6 and 20). It has the dimension of a length.

One should try to increase the cross section of the flow as much as possible† and try to obtain the maximum value of the ratio $(MS_a)^2/fS_w$ between heat transfer and friction.

When both the ratio MS_a/fS_w and the cross section (A) are kept constant, we can make the significance of this coefficient clearer by writing it

$$E = \pi \frac{A}{l} \left(\frac{MS_a}{fS_w} \right)^{1/2} \sin \beta \cos^{1/2} \beta \quad (29)$$

The maximum value of E is reached for $\tan \beta = 2^{1/2}$, but actually $\tan \beta = 1$ gives a value which is only 4% below this maximum. One should therefore try to get better heat transfer until one reaches the value, $MS_a = \pi A/l$ with:

$$E \approx 0.6 \, (MS_a)^{3/2}/(fS_w)^{1/2}$$

With a given channel cross section increasing values of heat transfer eventually bring diminishing returns due to the resulting increase in pressure drop and loss of reactivity caused by the use of extended surfaces.

* From heat-transfer considerations alone, CO_2 is a better coolant than He with extended surfaces above 300° C.

† This is only true when S_a is independent of A; for longitudinal fins, for instance, S_a decreases slowly with A for a given mass flow.

Conclusions

When the approximate characteristics of a nuclear power plant are to be found, one often starts with the value of the net electrical power—which has to be large enough to get a small capital cost per installed kilowatt. Moreover the maximum value of the pumping power is sometimes specified. Furthermore, since the cost per unit output decreases with an increase in net efficiency, one must try to obtain a good efficiency, ~25–30%. Since the maximum can temperature is fixed by metallurgical considerations, the operating point of the reactor can be drawn on the nondimensional diagram of Fig. 1 close to the lines already defined.

The values of θ_{avg} and P'_{eT} can then be deduced. For a given coolant and a given total mass of uranium, Eq. 28 shows that P'_{eT} is then proportional to the pressure, to the flattening factor F and to the aerothermodynamic factor E.

A compromise among the requirements for small pressure drop, pressure-vessel plate thickness and reactivity considerations will permit finding values of fuel-channel length, core diameter, coolant pressure, coolant-flow cross section, heat-transfer perimeter and wet perimeter.

The results obtained in this paper give but an order of magnitude of the various parameters. Several heat transfer experiments and nuclear computations are necessary for an actual design without oversimplification. The actual values of the parameters always result from compromise among all the different requirements in order to get a reliable power reactor with a low cost per unit output.

* * *

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Characteristics of VBWR

Location:	Vallecitos Atomic Laboratory, Pleasanton, Calif.
Owner—reactor plant:	General Electric Co.
—generating plant:	Pacific Gas & Electric Co.
Architect-engineer:	Bechtel Corp.
Cost—reactor plant:	$2,500,000
—generating plant:	$572,000
On line:	October 24, 1957
Output—heat:	30,000 kw
—electrical:	6,000 kw

Component Design Data

Pressure vessel

Inside height:	19.4 ft
Inside diameter:	7 ft
Wall thickness:	3⅜ in.
Composition:	carbon steel
Cladding	
—material:	stainless steel (304L)
—thickness:	0.125 in.
Design pressure:	1,215 psig
Test pressure:	1,825 psig

Core

Configuration:	cylinder
Size:	3 ft dia × 3 ft
Fuel load:	23 kg U^{235}
Composition	
—H_2O:	93 vol%
—UO_2:	0.25 vol%
—SS:	6.75 vol%

Control rods

Configuration:	blade
Number	
—12-in.-wide:	6
—5.75-in.-wide:	1
Poison:	B_4C
Total rod worth:	10% $\Delta k/k$
Weight	
—12-in. rod:	40 lb
—5.75-in. rod:	20 lb
Withdrawal rate:	4–12 in./min
Scram time:	0.25 sec

Control-rod drives

Type:	lead screw and nut
Number:	7
Power requirement:	120 v d-c
Motor rating:	1,750 rpm, ½ hp
Position indicator accuracy:	±1/25 in.

Fuel elements

Type:	plate
Number:	112
Enrichment:	> 90%
Plates per element:	6
Meat dimensions:	36 × 2.75 × 0.015 in.
Meat composition	
—UO_2:	23 wt%
—SS:	77 wt%
Cladding:	304L SS
Plate temp.	
—avg:	565° F
—max:	590° F

Nuclear Design Data

Moderator

Type:	light water
Thermal-neutron flux	
—avg:	2×10^{12} n/cm²/sec
—max:	5×10^{13} n/cm²/sec
Prompt-neutron lifetime:	5×10^{-5} sec
Eff. delayed-neutron fraction:	0.0075
Over-all temp. coefficient	$\sim -0.4 \times 10^{-5}$/° F

Control requirement

Burnup compensation:	1% $\Delta k/k$
Peak xenon override:	2% $\Delta k/k$
Equilibrium samarium:	0.7% $\Delta k/k$
Temperature coefficient:	0.5% $\Delta k/k$
Voids:	1% $\Delta k/k$
Total control available:	5.2% $\Delta k/k$

Heat Transfer Data

Coolant

Type:	light water
Volume—total:	12,000 liters
—in core:	520 liters
Inlet flow:	155 gpm
Inlet temperature:	100° F
Operating pressure:	1,000 psig
Outlet steam temp.:	545° F
Outlet steam flow:	57,000 lb/hr
Recirculation rate:	~ 50 lb/lb of steam

Heat flux

Max/avg ratio	
—axial:	1.6
—radial:	1.3
Core—average:	90,000 Btu/ft²/hr
—maximum:	200,000 Btu/ft²/hr
—burnout:	800,000 Btu/ft²/hr

NUCLEONICS REACTOR FILE . . . NO. 4

Reactors on the Line

VBWR

Vallecitos Boiling Water Reactor

REACTOR FILE . . . NO. 4

VBWR on the Line

VBWR went critical on August 5, 1957, and experiments to develop a core configuration most suitable for power operation were performed right in the reactor vessel. On August 31, GE was issued Power Reactor License No. 1 by the AEC and, after completion of the critical experiments, VBWR was initially operated at power on October 17. On October 19 the reactor developed its maximum licensed output. On October 24 (less than 17 months after ground breaking) the reactor went to full power and 6,000 kw of electricity began flowing through the Pacific Gas & Electric Co. transmission system. In excess of 1,000,000 kwh have been produced so far, and no technical difficulties have been experienced.

During the course of power operation, VBWR was found to be stable against load fluctuations and dynamic effects. The reactor easily generates its maximum licensed output, and fuel temperatures indicate a large heat-transfer margin. Neutron-flux distribution is flatter than was anticipated, and operation under boiling conditions is much smoother than was expected. GE now believes that VBWR is capable of producing substantially more than the 30 Mw(th) presently authorized.

tear along perforation

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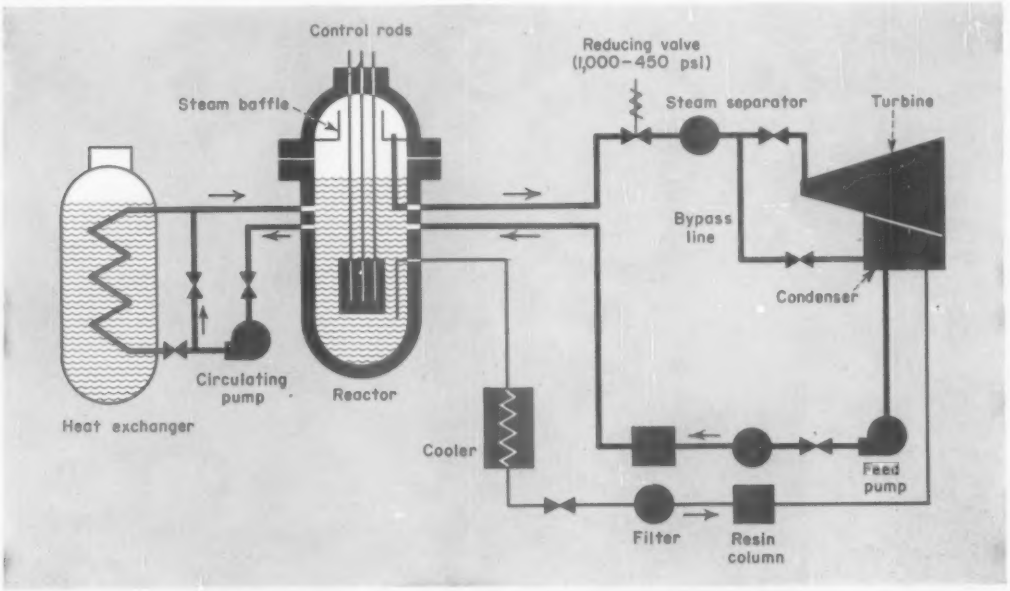
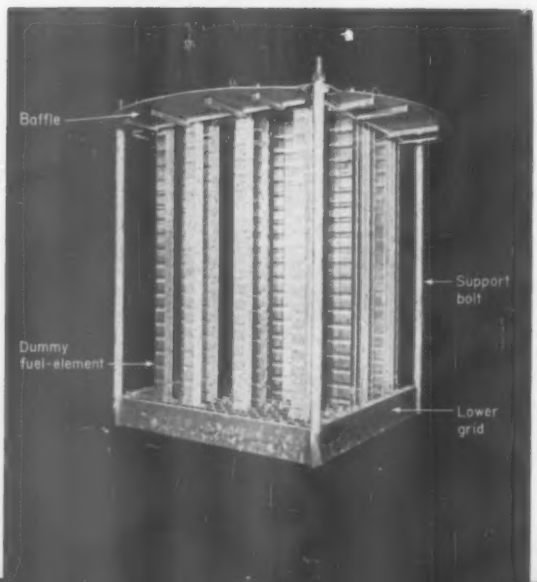
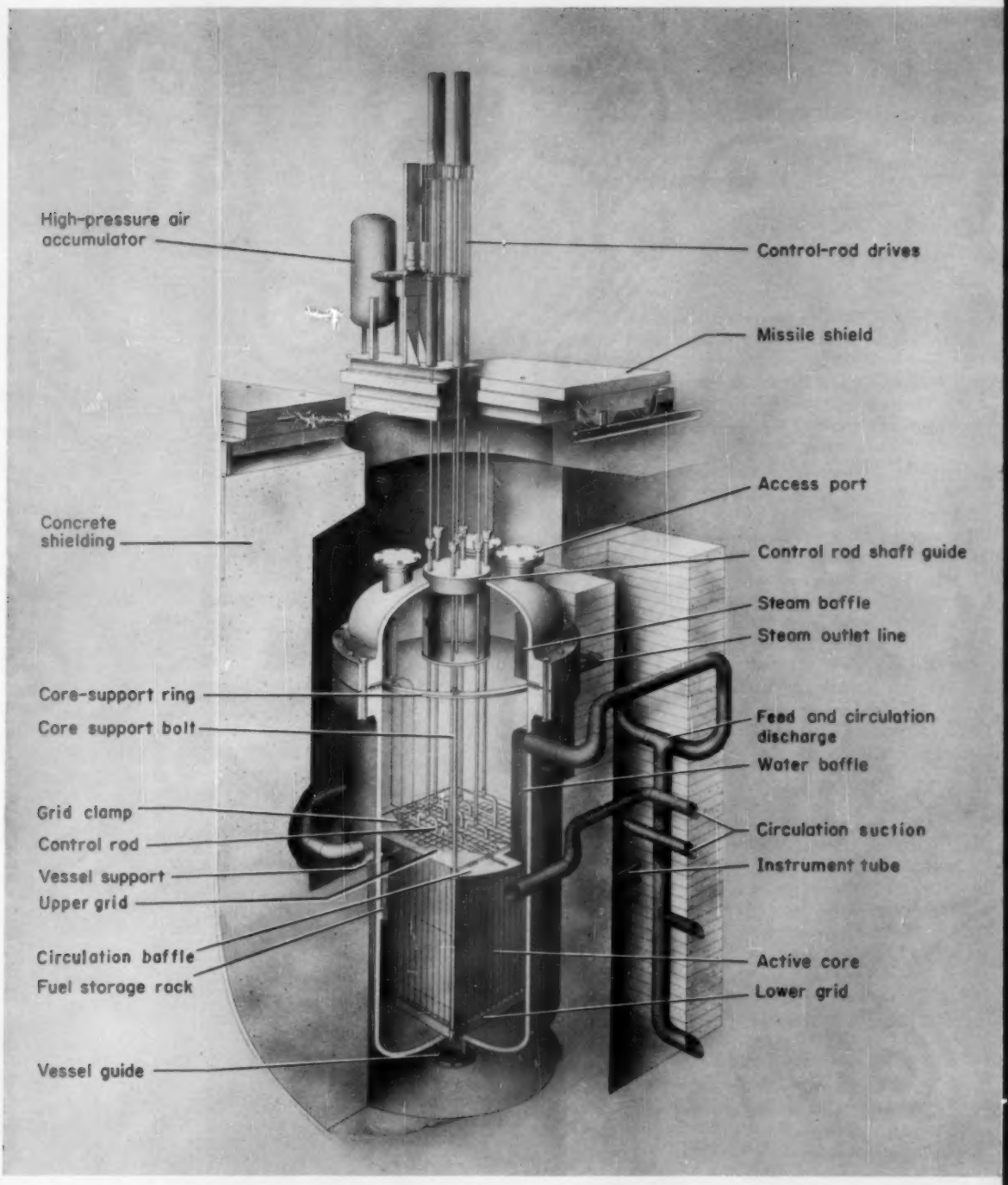


1 VBWR flow diagram. Although natural-circulation direct-cycle system, VBWR is provided with pump and steam generator in extra loop to simulate forced-circulation dual-cycle operation



2 Reactor-core structure is simple egg-crate-type; upper and lower grids are supported by long bolts. Dummy elements are here arranged arbitrarily; forced-circulation baffles are in lowered position



3 Reactor proper. Feedwater enters vessel above core and flows down through baffles to plenum below core then up through fuel elements. Water and steam leave core; water to flow down around outside of core to re-enter at bottom; steam to exit through baffle and pipe at top of vessel. For forced circulation, core baffles in lowered position (as shown) prevent downward flow of water; instead, it is pumped through extra loop and re-enters vessel as feedwater

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Description of VBWR

The Vallecitos Boiling Water Reactor (VBWR) has been constructed to serve as the following:

1. A test facility for certain critical components and parameters of the reactor GE is designing for the Commonwealth Edison Co. at Dresden, Ill.
2. A tool for the development, demonstration and testing of other boiling-water-reactor designs.
3. A training aid in the operation of a boiling-water reactor.
4. A research tool to provide reliable information concerning stability, load-response characteristics, safety and fuel economy of boiling-water reactors.

Pressure Vessel

The pressure-vessel shell was fabricated in four courses, each 37⅞ in. high, of SA264 steel plate clad on the inside with stainless steel. The upper head is fastened to the vessel shell with thirty-six 4-in. bolts through flanges that are 17 in. high and >9 ft o.d. A double gasket (soft-iron) arrangement incorporates means of collecting leakage.

A 9-in.-long piece of 12-in. pipe is welded to the bottom of the vessel and fits into a receptacle in the concrete under the vessel. This positions the vessel (but does not support it). The full weight of the vessel is carried by eight supports welded around the side about 8½ ft from the bottom. These rest on a leveling ring set into the concrete structure surrounding the vessel.

Two 10-in. inlet-water nozzles are located on each side of the vessel, 13½ ft above the bottom. Four 10-in. outlet-water nozzles are located 72 deg on either side of the centerline through the inlet nozzles, 9 ft above the bottom. A 6-in. outlet-steam nozzle is located 90 deg from the inlet nozzles, 13¾ ft above the bottom.

Seven nozzles for control-rod penetration extend 24 in. above a 7.25-in.-thick, 30-in.-o.d., SA105 (grade II) steel disk in the top of the upper head. Attached to the bottom of the disk is a stainless-steel shell that extends about 30 in. below the head and supports guide bushings for the control-rod shafts.

Four 12-in. nozzles, also located in the head, are access ports for refueling. One of these has a 1½-in. nozzle on the side for water-level control during refueling, and two of the others have 1-in. nozzles on the side to supply steam to the balancing cylinders on the control-rod drives. The four access ports are fabricated of carbon steel lined with stainless; all other nozzles are of stainless.

A water baffle, extending from each inlet nozzle down to 1 ft below the top of the upper grid of the core structure, directs the flow of incoming water to the bottom of the vessel. A steam baffle extends around the inside of the upper head with a pipe connecting it to the outlet-steam nozzle. This baffle serves to remove most of the water entrained in the steam.

Core Structure

The principal parts of the stainless-steel core structure are the upper and lower grids. These are suspended on support bolts from a ring that is supported by brackets attached to the pressure-vessel shell just below the flanges. The lower grid is an egg-crate structure supported in a square frame. The frame is fabricated of 7 × 2 × 1-in. angles welded together. Tubing welded to the corners of the frame is drilled and tapped to receive the support bolts.

The egg crate consists of nine support bars 3½ in. high and ⅝ in. thick in one direction and seventeen 6-in.-high grid bars in the other direction. Of the grid bars, 14 are ⅜ in. thick and three are ¾ in. thick. The grid bars are notched to fit over the support bars, which have grooves cut into them to position the grid bars. The egg crate provides uniform spacing of the fuel elements except where the ¾-in.-thick grid bars are located. These bars increase the separation between elements to permit passage of the control rods.

The upper grid consists essentially of a frame with six holddown grids hinged to it. The frame is fabricated from 1-in.-thick plate welded together. The hold-down grids are fabricated from ⅜-in. thick rods in an egg-crate arrangement. Each rod is notched so that all are interlocked and welded at each junction. Pieces of tubing 2 in. long, having a 1¼-in. o.d. and a ⅛-in. wall and milled so as to have four notches at right angles, are fitted over each junction and welded in place. After being welded, four more notches are cut in the tubes. When the holddown grids are lowered over the fuel elements, each tube engages the corners of four adjacent fuel elements. Clamps are provided to hold the grids in position.

The support ring is 2 in. thick and 4 in. wide. It is fastened to the brackets on the vessel wall by J-bolts and is fitted with adjusting screws. The four support bolts are of 1½-in.-diameter, hardened Armco 17-4PH stainless steel with Monel nuts. The bolts are slightly under 14 ft long and have 2¼-in.-o.d., ¼-in.-wall spacers of seamless tubing to establish the distance between the upper and lower grids and between the support ring and the upper grid.

Fuel Elements

The fuel elements are of the plate type, fabricated by the picture-frame technique. The fuel is in the form of UO_2 powder with particle sizes ranging from 44 to 80 microns. The diluent and cladding is type-304L stainless steel. Each plate is 37 in. long, 2.95 in. wide and 0.025 in. thick.

The fuel element consists essentially of six such plates and two side plates. The side plates are fabricated from 0.025-in.-thick, 3-in.-wide stainless-steel strips with indentations every 3½ in. These indentations are 0.05 in. deep and have a 5-in. radius of curvature. Six slots are punched into each indentation. The fuel plates are fitted into the slots and spot-welded in place. The side plates are 76.5 in. long. Two stainless-steel plates 28.25 in. long are fitted and spot welded into the outside slots above the fuel plates to provide a "chimney" for the coolant. Two 7-in.-long plates are similarly placed in the narrowed-down tip.

Control Rods

The control rods consist essentially of B_4C blocks enclosed in stainless steel. Six 12-in.-wide rods and one 5.75-in.-wide rod are arranged in three rows with the center row containing two large rods and the small one and the two outside rows containing two large rods spaced 9.7 in. from the center row. The rods in each row are separated by ½ in.

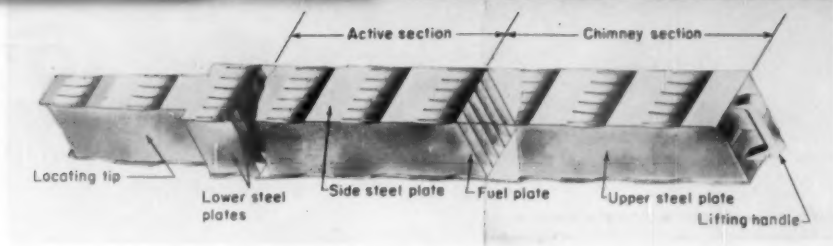
The absorbing section of the rod is 43 in. long. The B_4C blocks contained in this section are 2.87 in. square and ¼ in. thick. They are contained between 1/16-in. stainless-steel side and spacer plates. A piece of ⅜-in.-thick, 12-in.-wide stainless steel forms an extension 32 in. above the absorber section. Three holes, 8 in. square, are cut in the extension to reduce its weight. The B_4C blocks have a minimum density of 2.2 gm/cm³ and contain a minimum of 76.5% boron.

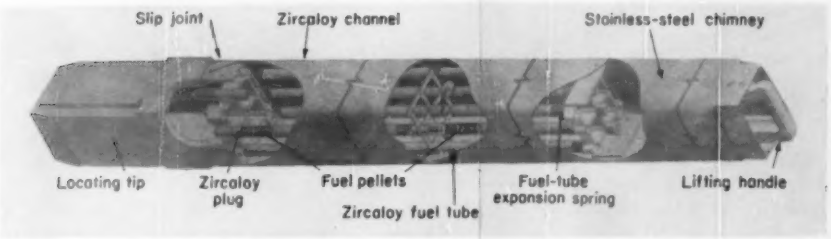
A short piece of 2½-in. stainless-steel rod is welded to the extension and is tapped to receive the control-rod-drive shaft extension. This extension is fabricated of Armco 17-4PH stainless-steel tubing with a 1½-in. o.d. and ⅛-in. wall.

Control-Rod Drives

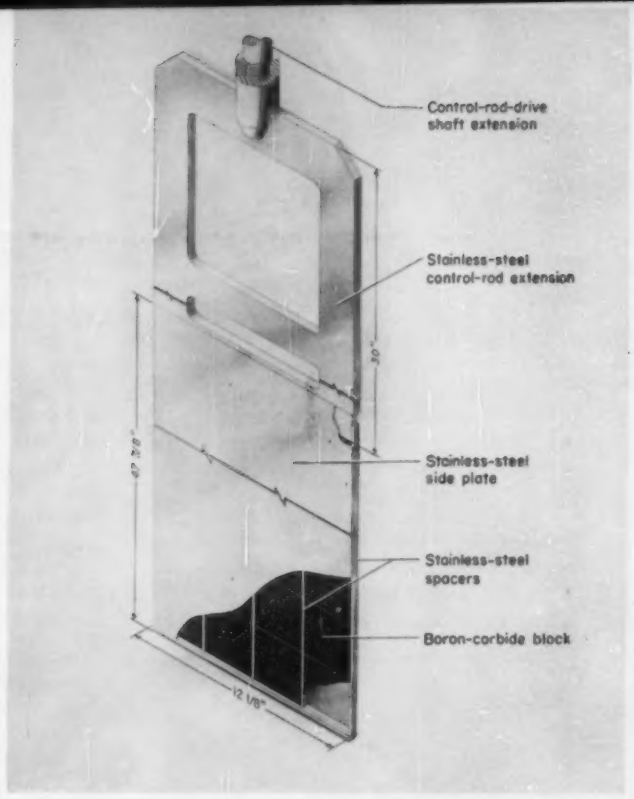
The seven drive units are mounted on a base plate that is attached to the missile shield above the reactor. All seven units are identical except for the one driving the center rod which, because of space limitations, is arranged differently—the motor is inverted and drives the lower end of the lead screws rather than the upper end.

The control-rod drives are patterned after those used in the Borax reactors. The actuating mechanism is a double-acting air cylinder with the piston attached to the drive shaft. Air pressure is applied to the lower side of the cylinder to drive the shaft up until a stop on the shaft contacts a motor-driven stop. When the motor-driven stop is moved up or down, the stop on the shaft and the control rod follows it. To scram the reactor, air pressure is removed from the lower part of the cylinder and a higher pressure is applied to the upper part. The piston is driven down by the air pressure, causing the stop on the shaft to separate from the motor-driven stop. A switch on the stop opens to cause the motor-driven stop to move down. When it contacts the stop on the shaft, the rod can be withdrawn. A balancing cylinder at the top of the shaft is connected to the reactor vessel so that the cylinder and motor-driven stop do not have to overcome reactor pressure but only the friction in the mechanism and seals.



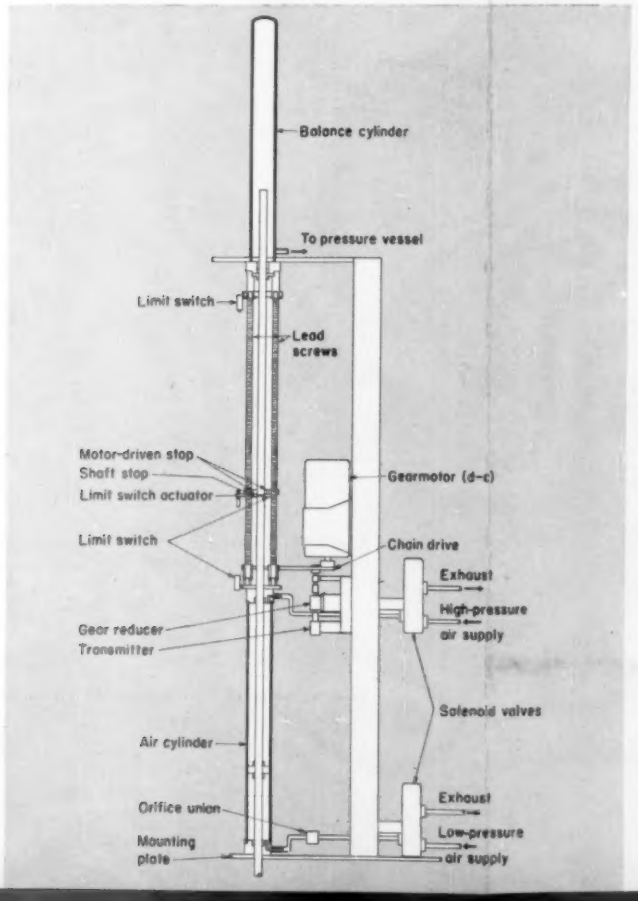


4 Initial core consists of 3-in.-square plate-type elements of simple design (top); two dimpled and slotted side plates hold six fully enriched fuel plates spot welded in place. Later core will consist of elements (bottom) similar to those of Dresden reactor. These will have either nine or sixteen ½-in.-diameter tubes containing 2.3% enriched UO_2 pellets clad with either stainless steel or Zr

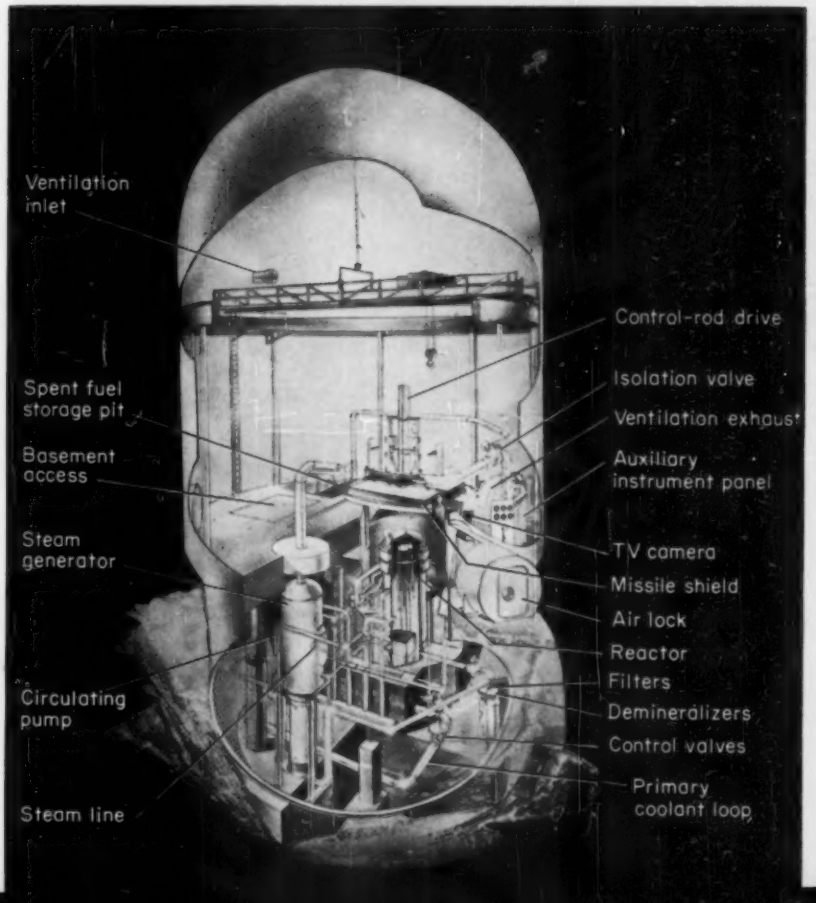


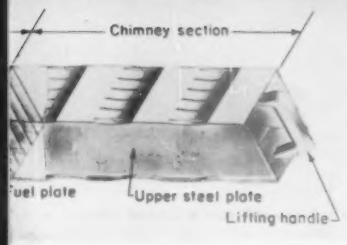
5 Blade-type control rods contain hot-pressed B_4C blocks encased in SS. Control-rod drive shaft extends through upper head of pressure vessel

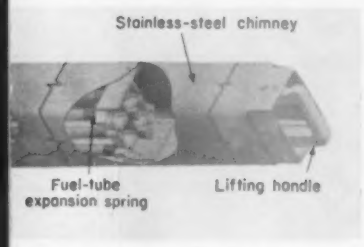
6 Control rods are positioned by variable-speed electric motors that operate lead screws against constant pressure of air cylinders. Drives mount on missile shield above reactor; simple disconnect joint is provided so that shield can be rolled away for refueling reactor



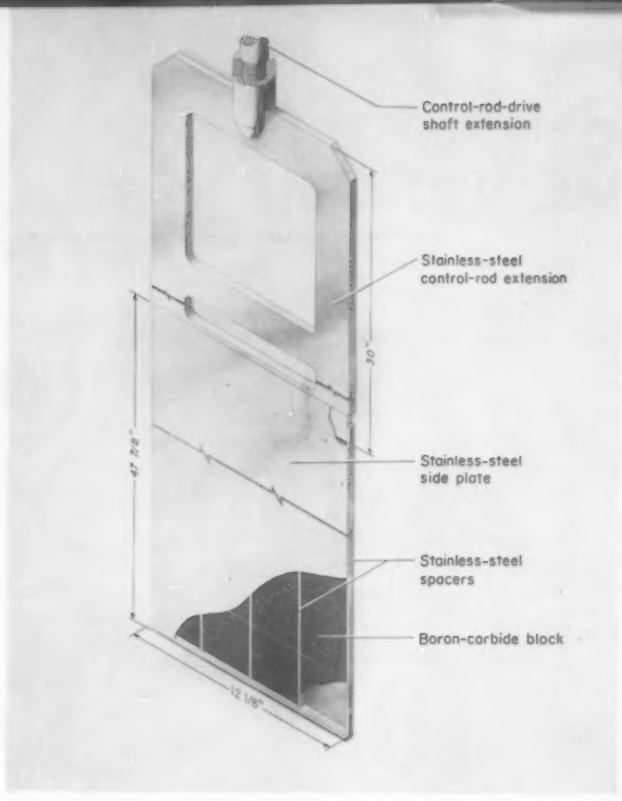
7 VBWR is housed in containment vessel 105 ft high over-all and 48 ft in diameter. Hemispherical heads were constructed of 7/16-in. SA212 steel plate; shell of ⅞-in. plate. Design pressure is 45 psig; test pressure is 56 psig. Shielding consists of concrete surrounding reactor and 80-ton missile shield on rollers over reactor







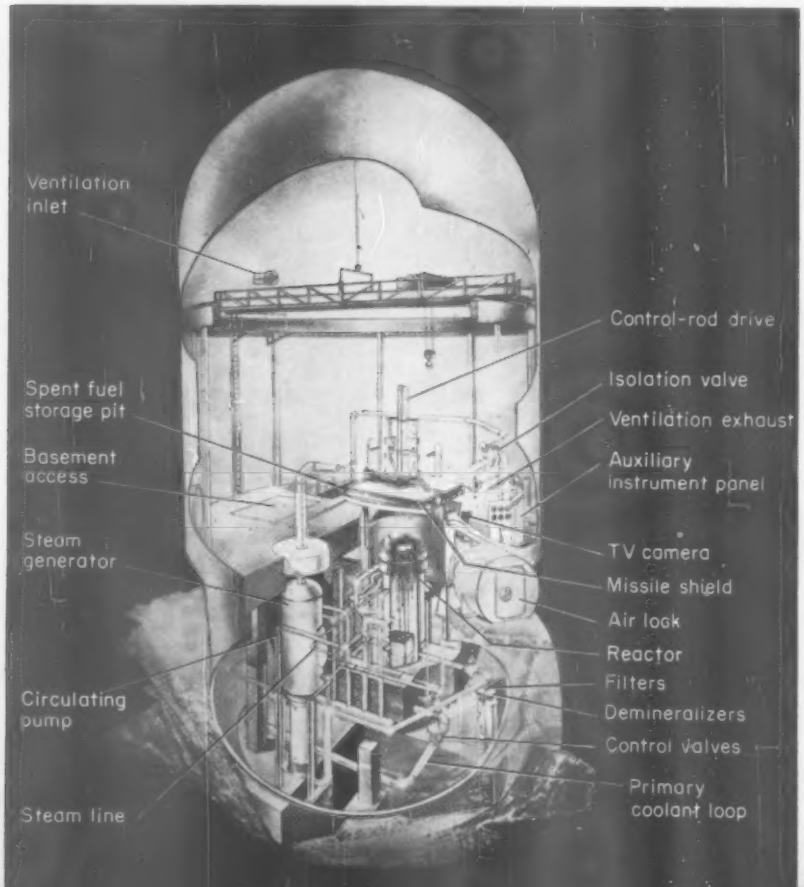
ients of simple design (top); two dimpled plates spot welded in place. Later core Dresden reactor. These will have either 3% enriched UO_2 pellets clad with either



s contain hot-pressed B_4C blocks encased in SS. extends through upper head of pressure vessel

ctric motors that of air cylinders. disconnect joint refueling reactor

7 VBWR is housed in containment vessel 105 ft high over-all and 48 ft in diameter. Hemispherical heads were constructed of 7/16-in. SA212 steel plate; shell of 7/8-in. plate. Design pressure is 45 psig; test pressure is 56 psig. Shielding consists of concrete surrounding reactor and 80-ton missile shield on rollers over reactor



Scenes like the above (at the 1957 Atomfair) will be repeated this year as . . .

Atomfair and Three Meetings Mark 1958 Nuclear Congress

PROGRESS IN THE USES of nuclear energy will be demonstrated March 17–21 when the nuclear industry meets in an even more comprehensive convention than last year's event. The headquarters for the 1958 Nuclear Congress will be the International Amphitheater in Chicago, Ill.

Guide to Nucleonics' Congress Coverage

Engineering papers . . p. 78
Management panels . p. 139
Hot Lab papers . . . . . p. 141
Atomfair exhibits . . . p. 144
Preprint order form . . p. 78

The Congress is being coordinated by the Engineers Joint Council. The Western Society of Engineers, a member of the Engineers Joint Council, will be the "host society." The American Power Conference is also participating to enable foreign representatives at this meeting to take part in the aspects of power generation that will be covered.

Headquarters hotel for the Congress will be the Palmer House. Information about advance registration and hotel reservations is available from any of the participating societies or from the Engineers Joint Council, 29 W. 39th St., N. Y. 18, N. Y.

The Congress will bring together four activities of major interest:

• **Fourth Nuclear Engineering and Science Conference** will present 150 papers on late developments in the several fields of atomic energy application, including a number of papers on aircraft propulsion. It is being sponsored by the American Nuclear Society and 28 other engineering and scientific societies.

• **Atomic Energy Management Conference,** sponsored jointly by the National Industrial Conference Board and the Atomic Industrial Forum.

• **Sixth Hot Laboratories and Equipment Conference,** sponsored by the Hot Laboratories Committee.

• **The Atomic Industrial Forum's "Atomfair"** will display the equipment, products and services of virtually every major supplier for the nuclear industry.

Extracurricular activities include luncheons sponsored by various societies at the Saddle & Sirloin Club adjacent to the amphitheater: Monday—ANS, Tuesday—AIChE, Wednesday—ASTM, Thursday—AIEE, Friday—ASME. In addition, Atomic Industrial Forum and National Industrial Conference Board will sponsor a "get acquainted" luncheon on Monday at Palmer House, a reception and dinner Tuesday beginning at 6:00 p.m. and a closing luncheon on Wednesday. The all-conference banquet will be held at Palmer House at 7:00 p.m. on Wednesday.

Preprints of conference papers (listed below) will be available after February 3rd and will cost 50 cents each. The preprints can be ordered with the coupon to be found on page 78. The order number of each paper is listed after the affiliation of the author.

Turn Page for Details on Congress Program

The 1958 Nuclear Congress at a Glance—

	MONDAY	TUESDAY
Nuclear Engineering and Science Conference		
MORNING 9:00 a.m.—12:00	Commercial Uses of Radioactive Tracers Reactor Component Development, Fabrication and Testing—I Standardization, Codes and Licensing Reactors for Process Heat and Radiation	Fuel, Control, Moderator and Coolant Materials—II Reactor Operation and Maintenance—II Experimental Power Reactors and Advanced Concepts—I Health Physics and Instrumentation
AFTERNOON 2:00—4:30 p.m.	Isotope Production and Application Reactor Component Development, Fabrication And Testing—II Reactor Operation and Maintenance—I Fuel, Control, Moderator and Coolant Materials—I	Reactor Physics Experimental Power Reactors and Advanced Concepts—II Temperature Measurements and High-Temperature Instrumentation Waste Treatment and Disposal
Atomic Energy Management Conference*		
MORNING 9:00 a.m.—12:00	Health and Safety Industry Assessment of the U.S. Power Reactor Program Selling Nuclear Products Outside the U.S. Are Small Reactors Economically Feasible?	Better Products Through Radioisotopes Reduction of Nuclear Power Costs Materials-Testing Facilities How the Indemnification Law is Working
AFTERNOON 2:00—4:30 p.m.	Power Reactor Experience Should the Atomic Energy Act be Amended? Outlook for Nuclear Ship Propulsion Nonnuclear Markets for Nuclear Materials	Prospects for Economic Nuclear Power Applications for Large Radiation Sources Developments in Thermonuclear Research Economics of Reactor Fuel Cycles

*International Atomic Energy Activities will be the subject of a panel Wednesday morning.

Nuclear Engineering & Science Conference Papers

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Monday, 9:00 a.m.—12:00

Commercial Use of Radioactive Tracers

Tracer Studies of Fungicidal Action—R. W. Greenlee, R. S. Davidson, H. T. Kemp, M. M. Baldwin, BMI 71

Radioactive Tracers in Extreme Pressure Lubrication—E. H. Loeser, R. C. Wiquist, S. B. Twiss, Chrysler Corp. 70

Location of Leaks with Radioisotopes in Multiwalled Tanks—W. F. Sullivan, Nat'l Lead Co. 75

Reactor Component Development, Fabrication and Testing—I

Diaphragm Feed Pumps for Homogeneous Reactors—C. H. Gabbard, ORNL 74

High Temperature Canned Motor Liquid Metal Pumps—Oliver P. Steele, III, Westinghouse 76

Guide to the Selection of Canned Motor Pumps—W. M. Wepfer, Westinghouse 77

Standardization, Codes and Licensing

A Review of Structural Evaluation Procedures—W. E. Cooper, GE-KAPL 78

Code Problems in the Design of Nuclear Power Plants—John Zickel, GE 79

Digest Program of the Week's Meetings

WEDNESDAY	THURSDAY	FRIDAY
Reactor Plant Instrumentation Fuel, Control, Moderator and Coolant Materials—III Reactor Location and Safety Thermal and Mechanical Design—I	Reactor Control Instrumentation—II Reactor Plant Materials—II Nuclear Education and Training Fuel Element Development, Fabrication and Testing—I	Reactor Systems Analysis—II Chemical Reprocessing—I Water Contamination and Treatment Reactor Shielding and Containment
Reactor Control Instrumentation—I Progress in Commercial Power Reactor Development Reactor Plant Materials—I Thermal and Mechanical Design—II	Reactor Safety Instrumentation Reactor Systems Analysis—I Fuel Element Development, Fabrication and Testing—II Research and Test Reactors and Critical Assemblies	Chemical Reprocessing—II

Hot Laboratories and Equipment Conference

Hot Cells and Process Facilities	Irradiation and Other Facilities Hot Laboratory Practices and Equipment	Hot Laboratory Safety
European Hot Laboratories	The Operational Aspects of Hot Laboratories	

Inspection and Testing of Pressure Piping as Related to Nuclear Power Plants—V. T. Malcolm, Sidney Low, Valve Mfg. Co. 132

Reactors for Process Heat and Radiation

The Chlorination of Mesitylene and Naphthalene in the Presence of Gamma Radiation—W. M. Sergy, J. F. Hanus, J. Oishi, J. J. Martin, L. C. Anderson, Univ. of Mich. 162

Monday, 2:00—4:30 p.m.

Production and Application of Radioisotopes

The Release of Strain in Prince Rupert's Drops by Gamma Irradiation—C. H. Greene, N. Y. State Ceramic College 45

The Use of Tritium as an Ionizing Source in Instruments—G. Frederick Vanderschmidt, J. R. Roehrig, John C. Simons, Jr., Nat'l Research Corp. 60

The Effect of Nuclear Radiation on the Behavior of Cellulose and Cellulose Derivatives—Otto Teszler, Henry A. Rutherford, N. C. State College 48

Recovery of Radioactive Cesium at Hanford—B. F. Judson, R. L. Moore, H. H. VanTuyl, GE-HAPO

Density Measurement of Saturated, Submersed Sediment by Gamma Ray Scattering—Lloyd O. Timblin, Jr., U. S. Department of the Interior, Bureau of Reclamation 135

Kilocurie Production of Barium-140—B. M. Legler, A. L. Ayers, Phillips Petroleum Co. 136

Reactor Component Development, Fabrication and Testing—II

Control Rod Drive Mechanism for the Argonne Low Power Reactor—W. J. Kann, ANL 30

Development of a Welded Seal for a Reactor Vessel Head—Kenneth B. Garner, James W. Rogers, Combustion Engineering 167

Control Rod Drive Mechanisms for Pressurized Water Reactors—J. J. Gerts, J. W. Flaherty, Westinghouse 80

Control Valves for the Homogeneous Reactor Test—A. M. Billings, ORNL 149

Reactor Operation, Maintenance—I

Startup and Operation of the Sodium Reactor Experiment—L. E. Glasgow, Atomics International 81

Direct Maintenance Practices for the Homogeneous Reactor Test—S. E. Beall, ORNL, R. W. Jurgensen, Ohio Power Co. 82

Testing Required for Full Power Operation at Shippingport Atomic Power Station—S. G. Schaffer, Duquesne Light Co. 83

Fuel, Control, Moderator and Coolant Materials—I

Comparison of the Active with the Inactive Uranium Dioxide-Oxygen System—D. A. Vaughan, R. K. Willardson, BMI 13

Metallurgical Design and Properties of Silver-Indium-Cadmium Alloys for PWR Control Rods—I. Cohen, E. F. Losco, J. D. Eichenberg, Westinghouse 19

Effects of Pile Irradiation on U_3Si—M. L. Bleiberg, L. J. Jones, Westinghouse 18

Radiolytic and Pyrolytic Decomposition of Organic Reactor Coolants—D. R. de Halas, GE 23

Some Aspects of the Use of an Organic Coolant in a Heavy Water Moderated Power Reactor—Malcolm J. McNelly, Canadian GE 20

Tuesday, 9:00 a.m.—12:00

Fuel, Control, Moderator and Coolant Materials—II

The Effects of Transformation Cooling Rate on the Activation Energy Required for Recrystallization of Beta Quenched

continued on p. 134

Radionuclides Arranged by Gamma-Ray Energy

By GILBERT W. SMITH and DONALD R. FARMELO
Curtiss-Wright Corp., Quehanna, Pennsylvania

THE TABLE presented here lists radionuclides in order of the energies of their emitted photons. The listing covers the literature to October, 1956, as given by the Table of Isotopes (*1*) and the annual cumulations of nuclear data in Nuclear Science Abstracts.

The following criteria have been used in selecting the items:

- Nuclides derived from n,γ reactions and fission products having $>\sim 0.5\%$ yield are included.
- Half-lives or precursor half-lives are a few minutes or longer.
- Gammas $<10\%$ of the total activity of any nuclide are omitted.

For use in identifying nuclides by gamma-scintillation spectrometry, the list includes other data along with photopeak energy. The list is also useful in finding photon energies for calibration purposes.

Photopeaks must not be confused with other peaks (*2*): (a) Pair-production peaks appear 0.51 and 1.02 Mev below the photopeak and are especially bothersome if the photopeak occurs above 1.5 Mev. (b) Annihilation radiation appears at 0.51 Mev in positron emitters. (c) Compton collisions that scatter the photon at 180 deg create a peak at the following energy: $E = E_0/(1 + 3.9137E_0)$ with both energies in Mev (*3*). (d) The energy of the K_α X-ray line in kev can be computed from its wave length λ in angstroms as $12.34/\lambda$.

Radiochemical separations may be necessary before using the table if a complex mixture has more than 5 photopeaks. Half-life, detection efficiency, daughter activities, and other properties can be used to resolve situations of this kind.

BIBLIOGRAPHY

1. J. M. Hollander, I. Perlman, G. T. Seaborg, *Revs. Mod. Phys.* **25**, 469 (1953)
2. P. R. Bell, "The Scintillation Method," in "Beta and Gamma-Ray Spectroscopy," K. Siegbahn, ed. (Interscience Publishers, New York, 1955)
3. B. Crasemann, H. Easterday, NUCLEONICS **14**, No. 6, 63 (1956)

Radionuclides by Increasing Gamma-Photon Energy

Photopeak energy (Mev)	*Nuclide*	*Half-life*	*Production cross section* (barns) or fission yield (%)*	*Photon yield per disintegration (%)*	*Daughter*
0.037	Br^{80m}	4.58h	2.9b	100	Br^{80}
0.040	Rh^{103m}	57m	2.9%	100	Rh^{103}(st) †
0.047	Pb^{210}	22y		~100	Bi^{210}
0.049	Br^{80m}	4.58h	2.9b	100	Br^{80}
0.052	Rh^{104m}	4.4m	12b	100	Rh^{104}
0.058	Gd^{159}	18h	4b		Tb^{159}(st)
0.068c‡	Ta^{182}	112d	21b		W^{182}(st)
0.077	Pt^{197}	10h	1.1b	100	Au^{197}(st)
0.080	Ho^{166}	27.3h	60b		Er^{166m}
0.081	Xe^{133}	5.27d	6.5%		Cs^{133}(st)
0.084	Tm^{170}–Yb^{170m}	129d	125b		Yb^{170}(st)
0.084	Th^{228}	1.9y		28	Ra^{224}
0.087	Pd^{109}	13.6h	12b		Ag^{109m}
0.089	Lu^{176m}–Hf^{176m}	3.7h–short	40b	100	Hf^{176}(st)
0.089	Te^{127m}	110d	0.09b		Te^{127}
0.092	Nd^{147}	11.3d	1.8b,2.6%		Pm^{147}
0.093	Th^{234}	24.1d		20	Pa^{234}
0.094	U^{235}	7.1×10^8y			Th^{231}
0.100	Sm^{153}	47h	140b		Eu^{153m}
0.103	Dd^{153}	236d	<125b		Eu^{153}(st)
0.105	Pa^{233}	27.4d	~50b		U^{233}
0.105	Sm^{155}	2.4m	5.5b	100	Eu^{155}
0.106	Te^{129m}	33.5d	.015b,0.34%	100	Te^{129}
0.110	Te^{125m}	58d	5b	100	Te^{125}(st)
0.112	Lu^{177}	6.8d	4×10^3b		Hf^{177}(st)
0.113c	Er^{171}	7.5h	9b		Tm^{171}
0.123c	Eu^{154}	16y	420b		Gd^{154}(st)
0.128	Cs^{134m}	3.2h	0.016b	100	Cs^{134}
0.129	Os^{191}	16.0d	8b	100	Ir^{191}(st)
0.132	Hf^{181}	46d	10b		$Ta^{181m_2m_1}$
0.134	Ce^{144}	290d	6.0%	30	Pr^{144}
0.136c	Se^{75}	127d	26b		As^{75}
0.140	Te^{99m}	6.04h	5.8%	99	Te^{99}
0.142	Ce^{141}	32.8d	0.3b,5.7%	67	Pr^{141}(st)
0.147	Te^{131}	24.8m	0.22b,2.9%	55	I^{131}
0.150	Cd^{111m_2}	49m	0.2b	100	Cd^{111m_1}
0.150	Kr^{85m}	4.36h	0.1b,1.1%		Kr^{85}
0.155	Re^{188}	16.9h	70b		Os^{188}(st)
0.16	Ba^{140}	12.8d	4.0b,6.3%	60	La^{140}
0.16	Xe^{131m_2}	12.0d	2.9%	§	Xe^{131}(st)
0.162	Ba^{139}	85.0m	0.5b,6.2%	26	La^{139}
0.176	Se^{83}	25m	0.004b		Br^{83}
0.177	Te^{131m}	30h	0.42%		Te^{131}
0.180	Ta^{182m}	16.5m	0.03b	100	Ta^{182}
0.184	U^{235}	7.1×10^8y			Th^{231}
0.188	Ra^{226}	1622y		6	Ru^{222}
0.190	In^{114m}	49d	56b	100	Cd^{114}
0.191	Mo^{101}	14.6m	0.20b,5.4%		Te^{101}
0.206	Lu^{177}	6.8d	4×10^3b		Hf^{177}(st)
0.216c	Hf^{180m}	5.5h	75b	100	Hf^{180}
0.231	Te^{132}	77.7h	4.4%	40	I^{132}
0.234	Xe^{133m}	2.3d	6.5%	100	Xe^{133}

Photo-peak energy (Mev)	Nuclide	Half-life	Production cross section* (barns) or fission yield (%)	Photon yield per disinte-gration (%)	Daughter
0.239	Pb^{212}	10.6h		~80	Bi^{212}
0.244c	Eu^{152}	13y	7×10^3b		Gd^{152}(st)
0.246	Cd^{111m_1}	49m	0.2b	100	Cd^{111}(st)
0.250	Xe^{135}	9.13h	5.9%	100	Cs^{135}
0.25	Sm^{155}	24m	5.5b	100	Eu^{155}
0.26c	Ge^{77}	12h	0.2b		As^{77}
0.265	Ge^{75}	82m	0.5b		As^{75}(st)
0.265c	Se^{75}	127d	26b		As^{75}
0.279	Hg^{203}	47d	3.8b	100	Tl^{203}(st)
0.284	I^{131}	8.05d	2.9%		$Xe^{131m_2m_1}$
0.285	Pm^{149}	50h	1.3%		Sm^{149}(st)
0.290	Ce^{143}	33h	1.0b,5.4%		Pr^{143}
0.305	Kr^{85m}	4.36h	0.1b,1.1%		Kr^{85}
0.307	Tc^{101}	14m	5.4%		Ru^{101}(st)
0.31c	Pa^{233}	27.4d	50b		U^{233}
0.316c	Ir^{192}	74.4d	700b		Pt^{192}(st)
0.32	Nd^{147}	11.3d	1.8b,2.6%		Pm^{147}
0.325	Cr^{51}	27d	11b	9	V^{51}(st)
0.326	Sn^{125}	9.5m	0.2b		Sb^{125}
0.33c	Ir^{194}	19h	130b		Pt^{194}(st)
0.335	Cd^{115}–In^{115m}	53h–4.5h	1.1b		In^{115}(st)
0.35	Bi^{211}	2.16m		16	Tl^{207}
0.36	Gd^{159}	18h	4b		Tb^{159}(st)
0.364	I^{131}	8.05d	2.9%	80	$Xe^{131m_2m_1}$
0.37	Ni^{65}	2.56h	2.6b	15	Cu^{65}(st)
0.37	Se^{83}	25m	0.004b		Br^{83}
0.388	Sr^{87m}	2.8h	1.3b	100	Sr^{87}
0.393	Sn^{113}	118d	1.3b		In^{113m}
0.41c	Kr^{87}	78m	2.7%		Rb^{87}
0.412	Au^{198}	2.69d	96b	99	Hg^{198}
0.44	Zn^{69m}	13.8h	0.1b	100	Zn^{69}
0.444c	Hf^{180m}	5.5h	75b	100	Hf^{180}
0.45	I^{128}	25m	6.3b	7	Xe^{128}(st)
0.468c	Ir^{192}	74.4d	700b		Pt^{192}(st)
0.479	Be^{7}	52.9d		11	Li^{7}(st)
0.48	W^{187}	23.9h	34b		Re^{187}(st)
0.490	La^{140}	40.0h	8.4b		Ca^{140}(st)
0.498	Ru^{103}	39.8d	1.2b,2.9%	99	Rh^{103m}
0.513	Sr^{85}	65d	1.0b	100	Rb^{85m}
0.513	Ru^{106}–Rh^{106}	1y–30s	0.38%	11	Pd^{106}(st)
0.52	Si^{31}	2.65h	0.11b		P^{31}(st)
0.52	Xe^{135m}	15.6m	6.3%	100	Xe^{135}
0.53	I^{133}	20.9h	6.5%	94	$Xe^{133,133m}$
0.53	Nd^{147}	11.3d	1.8b,2.6%		Pm^{147}
0.537	Ba^{140}	12.8d	6.3%,4.0b	30	La^{140}
0.541	Br^{82}	35.7h	3.5b		Kr^{82}(st)
0.549	As^{76}	26.5h	4.2b	50	Se^{76}(st)
0.55	Sr^{91}	9.7h	5.8%		Y^{91}
0.56c	Ge^{77}	12h	0.2b		As^{77}
0.564	Sb^{122}	2.75d	7b		Te^{122}(st)
0.605	Sb^{124}	60d	2.5b	50	Te^{124}(st)
0.609c	Bi^{214}	19.7m			Po^{214}
0.62c	Br^{82}	35.9h	2.6b		Kr^{82}(st)
0.624	Ru^{106}–Rh^{106}	1y–30s	0.38%	12	Pd^{106}(st)
0.637	I^{131}	8.05d	2.9%	9	$Xe^{131m_2m_1}$
0.657	Ag^{110m}	270d	2.8b	97	Ag^{110}
0.662	Cs^{137}–Ba^{137m}	33y–2.6m	5.9%	92	La^{137}
0.673	I^{132}	2.26h	600b		Xe^{132}(st)
0.69	W^{187}	23.9h	34b		Re^{187}
0.7	Te^{131}	24.8m	0.22b	45	I^{131}
0.72	Zr^{95}	65d	0.10b,6.3%	99	Nb^{95}
0.726	Ru^{105}	4.5h	0.7b,0.85%	100	Rh^{105m}
0.740	Mo^{99}	68h	0.13b,6.1%	20	Tc^{99}
0.764	Nb^{95}	35d	15b,6.3%	100	Mo^{95}(st)
0.77c	Br^{82}	35.9h	2.6b		Kr^{82}(st)
0.775	Zr^{97}–Nb^{97m}	17.0h–60s	6.1%	100	Nb^{97}
0.796	Cs^{134}	2.3y	26b	~80	Ba^{134}(st)
0.829	Pb^{211}	36.1m		13	Bi^{211}
0.83c	Ga^{72}	14.3h	4.6b		Ge^{72}(st)
0.835	Mn^{54}	291d		100	Cr^{54}(st)
0.835	Ga^{72}	14.3h	3.4b	100	Ge^{72m}
0.845	Mn^{56}	2.58h	13.4b	100	Fe^{56}(st)
0.88	Sc^{46}	84d	12b	99.5	Ti^{46}(st)
0.91c	Rb^{88}	17.8m	0.14b		Sr^{88}(st)
0.95	Cd^{115}–In^{115m}	53h–4.5h	1.1b		In^{115}(st)
0.95	Se^{83}	25m	0.004b		Br^{83}
0.96	Mo^{101}	14.6m	0.20b,5.4%		Tc^{101}
0.96c	Tb^{160}	73d	44b		Dy^{160}(st)
1.0c	Dy^{165}	2.32h	2.7×10^3b		Ho^{165}(st)
1.08	Rb^{86}	18.7d	0.7b	20	Sr^{86}(st)
1.097	Fe^{59}	46d	0.9b	50	Co^{59}(st)
1.11	Zn^{65}	245d	0.5b	45	Cu^{65}(st)
1.11	Sc^{46}	84d	12b	99.5	Ti^{46}(st)
1.12c	Eu^{154}	16y	4.2×10^3b		Gd^{154}(st)
1.12	Ni^{65}	2.56h	2.6b	30	Cu^{65}(st)
1.12c	Ta^{182}	112d	21b		W^{182}(st)
1.172	Co^{60}	5.27y	20b	99	Ni^{60}(st)
1.27c	In^{116m}	54m	150b	75	In^{116}
1.27	I^{135}	6.75h	6.3%		$Xe^{135,135m}$
1.277	Na^{22}	2.60y		100	Ne^{22}(st)
1.29	A^{41}–K^{41m}	109m–short	0.53b	99	K^{41}(st)
1.295	Fe^{59}	45.0d	0.9b	50	Co^{59}(st)
1.332	Co^{60}	5.27y	20b	99	Ni^{60}(st)
1.36	Ho^{166}	27.3h	60b	11	Er^{166m}
1.38	Na^{24}	14.90h	0.56b	100	Mg^{24}(st)
1.4	V^{52}	3.77m	4.5b		Cr^{52}(st)
1.44c	Cs^{138}	32.9m	5.7%	100	Ba^{138}(st)
1.49	Ni^{65}	2.56h	2.6b	15	Cu^{65}(st)
1.53	K^{42}	12.44h	1.0b	20	Ca^{42}(st)
1.57	Cl^{38}	37.3m	0.6b	31	A^{38}(st)
1.60	Cl^{38}	37.3m	0.6b	31	A^{38}(st)
1.60	La^{140}	40.3h	8.4b		Ce^{140}(st)
1.61	Pr^{142}	19.21h	10b		Nd^{142}(st)
1.78	Al^{28}	2.27m	0.23b	100	Si^{28}(st)
1.8	I^{135}	6.75h	6.3%		$Xe^{135,135m}$
1.81	Mn^{56}	2.58h	13.4b	30	Fe^{56}(st)
1.85c	Rb^{88}	17.8m	0.14b		Sr^{88}(st)
2.15	Cl^{38}	37.3m	0.6b	47	A^{38}(st)
2.62	Tl^{208}	3.1m		100	Pb^{208}(st)
2.76	Na^{24}	14.90h	0.56b	100	Mg^{24}(st)
2.8c	Rb^{88}	17.8m	0.14b		Sr^{88}(st)

* Thermal-neutron cross section of target atom.
† (st) = stable element.
‡c = complex spectrum.
§1% abundant in I^{131}.

FUEL REPROCESSING SERIES—3

Treatment and Disposal of Fuel-Reprocessing Waste

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MANY SCHEMES are now being studied for the treatment and ultimate disposal of highly radioactive wastes. The major source of these wastes will be the reprocessing of reactor fuels, as described in the previous articles in this series.*

Several methods are under investigation for treating high-level wastes to enable their safe, ultimate disposal. The most promising is the fixation of fission products in inert solids.

Present handling methods are generally of a short-term nature. Studies are being initiated of direct ultimate disposal systems, i.e., disposal into specially selected geologic formations. The primary objective of ultimate disposal is that the waste be (a) in an immobile or inert form or (b) restricted in a particular location for long periods of time so that in either case it will not constitute a biological hazard.

Two major factors set the nuclear-waste problem apart from other industrial waste situations:

1. We must control the radioactive waste products for hundreds of years. This may be a longer period than the life of any political entity or corporate system.

2. The extremely low concentrations of fission products permissible in man's environment demand a much more meticulous control than do nonradioactive situations.

These factors are complicated by the delayed, and therefore essentially unknown, long-term radiation effects.

Waste Characteristics

The various waste materials evolving from the aqueous processing (solvent extraction) of nuclear-reactor fuels are summarized in Table 1 (*2*). The very-high-activity aqueous waste stream from the first cycle of a solvent-extraction process is the major source of high-level wastes. It is likely that for a number of years this will continue to be the case.

Chemical and physical nature. As noted in previous articles in this series, existing solvent-extraction processes for plutonium production or for recovery of enriched uranium from U-Al alloys are not necessarily those that will be used for reprocessing proposed fuels. Nevertheless, enough is known to make it possible to list approximate characteristics expected for first-cycle wastes (*3*), as in Table 2. These wastes contain substantial concentrations of ions other than fission products. In many cases such inactive diluents limit volume reduction by evaporation.

Radioactivity. Analyses (*2–5*) have

* "Fuel Reprocessing—1, Fuel Reprocessing by Aqueous Methods" (NU, Oct. '57, p. 72); "2, Low-Decontamination and Volatility Methods" (Dec. '57, p. 44).

TABLE 1 — Radioactive Effluents from Process Operations

Source	*Activity level*	*Important constituents*
Gases		
Dissolving	Moderate	Kr, (I_2), particles, (H_2), NO
Process vessels	Low	Particles, air, acids
Ventilation	Very low	Particles, air
Liquids		
First raffinate	High	Acids, salts, F.P.'s
Later raffinates	Moderate	Similar to above
Used solvent	Low	Kerosenes, TBP, I_2, Ru
Solvent washes	Low	NaOH, Na_2CO_3
Condensates	Very low	H_2O
Solids		
Filter cakes	Moderate–high	MnO_2, cyanides, SiO_2
Gas-filter media	Low	Glass, metal, asbestos, paper
Contaminated rags, paper	Low	Chiefly cellulosic
Contaminated equipment	Low	Metals

been made of the future accumulation of radioactive wastes (fission and neutron-capture products) and of the resultant potential environmental hazard.

Table 3 (*2*) shows the radioactivities that would accumulate in a relatively modest nuclear-power program extending over ten years and the activities that remain after a ten-year decay of this accumulation. When these latter activities are compared with presently acceptable drinking-water concentrations, it is apparent that even if critical isotopes such as Sr^{90}, Cs^{137} and Pu^{239} could be quantitatively removed from the waste stream, interim storage of the order of ten years would still be required.

All workers in this field have suggested the desirability, under some circumstances, of removing Sr^{90} and Cs^{137} from first-cycle waste streams (*3*). This presupposes: (a) that satisfactory ultimate-disposal systems for Sr and Cs will be available, (b) that heat can be satisfactorily removed from fission-product concentrates and (c) that the remaining waste stream is sufficiently decontaminated to permit safe dispersal to the environment or that other practical systems are available. Dispersal to the environment automatically requires decontamination factors for Sr of 10^6 or greater and also that the isotopes remaining in the bulk stream decay in reasonable times (2–10 yr) to safe disposal levels. This, in turn, may be complicated by the possible presence of transuranics in the bulk stream.

Predisposal Treatment

Waste-treatment systems for use prior to ultimate disposal can be categorized as storage, evaporation, neutralization, precipitation, ion exchange, crystallization and fixation.

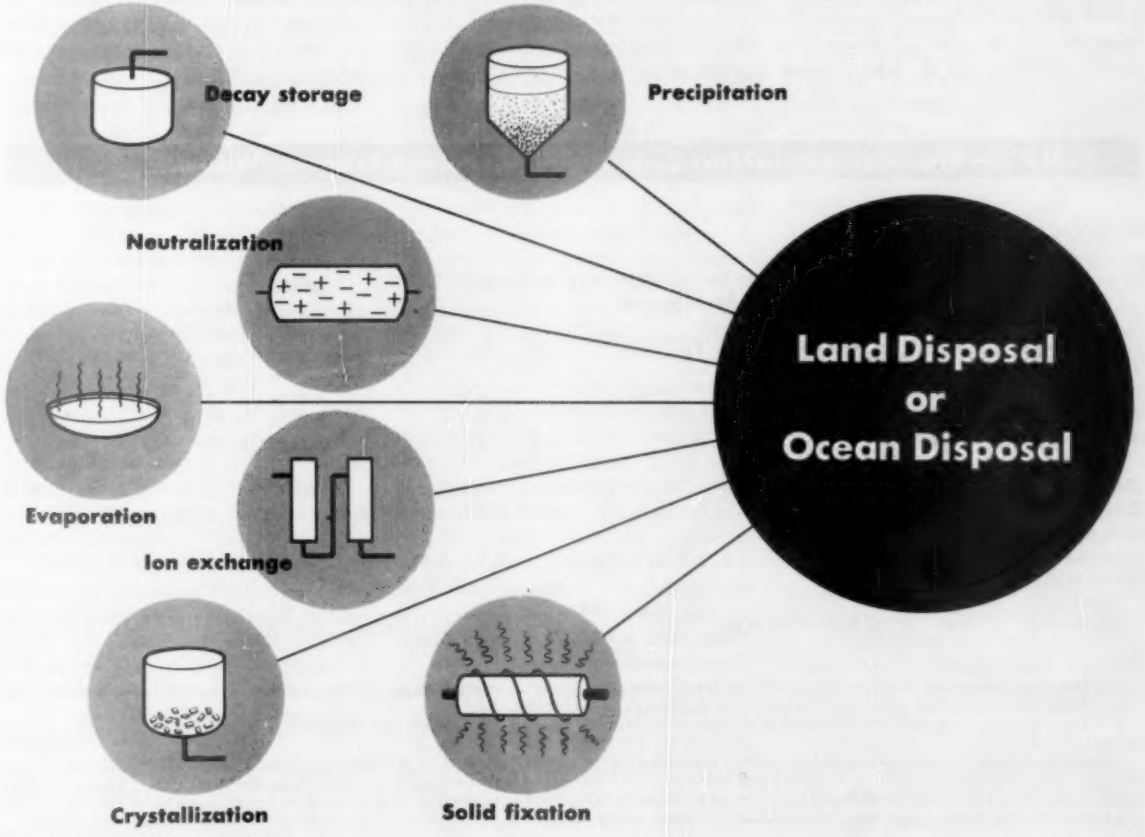
Storage. Storage includes holdup of wastes to permit radioactive decay and, conceivably, long-term storage as an ultimate disposal system in itself.

Storage-tank installation design and operation has been described by Platt (*2*). Figures 1 and 2 show a typical high-level-waste tank-farm installation at Hanford and a close-up of a Savannah River tank. Table 4 summarizes the costs of high-level-waste tank installations. These data emphasize the need to develop fuels and fuel-processing systems that result in smaller waste volumes.

The limitations of tank storage should be noted. Tank construction cost is significant and the useful life is uncertain. At the present time, however, it appears that tank storage will always be an important waste-handling step in an ultimate disposal system. Moreover, tank storage is the only available system possessing the required degree of containment and control.

Stored high-level wastes release sufficient decay heat to enable self-concentration in the storage tanks. These tanks are generally equipped with reflux condensers so that self-reduction of volume can be essentially cost-free;

Waste May Be Treated in These Ways Prior to Disposal



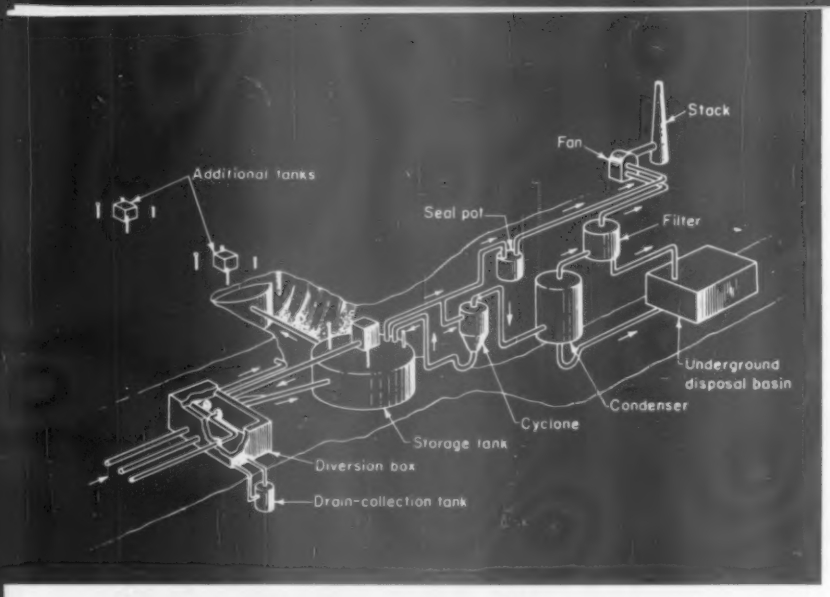


FIG. 1. Hanford high-level-waste storage facility. Fuel-processing wastes are stored in steel-lined, reinforced-concrete tanks. Condenser removes radioactive-decay heat. Diversion box routes wastes to tanks. Each tank has capacity of 500,000–1,000,000 gal

it has been estimated (*3*) that neutralized Purex-type wastes can thus be reduced in volume by a factor of 4–6. Certain operational problems have been met in this regard. Tank pressures slightly higher than atmospheric can occur if the wastes boil unevenly. Wastes at the bottom of the tank are under sufficient hydrostatic pressure to raise its boiling point by several degrees. Movement of the tank contents due to convection or movement of solids may create a local rising of the waste, which results in decreased hydrostatic pressure and boiling. The rising of the solution is accelerated by the vapor acting as a gas lift. Pressures up to 60 in. of water and vapor-evolution rates up to 50 times the average have been observed (*2*). This behavior can be controlled by mild agitation of the tank contents.

Evaporation. Evaporation prior to storage is generally economic for reducing storage volume.

The degree to which evaporation is carried out is limited in some instances by the percentage of solids present in the waste or by corrosion considerations. Carry-over of radioactivity to the condensate through entrainment must be carefully controlled since decontamination factors of 10^8 or greater from feed to condensate may be required.

Table 5 (*2*) summarizes evaporator performance. Cost experience with waste evaporation is summarized in Table 6 (*3*).

Neutralization. Neutralization is employed primarily to reduce corrosion problems. When wastes are neutralized their solids content is increased, and volume reduction by evaporation may be restricted. This in turn is reflected in increased tank requirements and perhaps costs, depending upon the economic balance between materials of construction and tank size.

Precipitation. Precipitation processes are used to separate out the bulk diluents of aqueous-waste raffinates to permit greater volume reduction. It can also be used in conjunction with proposed ion-exchange schemes noted later.

TABLE 2 — Characterization of First-Cycle, High-Level Solvent-Extraction Wastes*

	Constituent concentrations (molar) exclusive of fission products and heavy elements												*Waste† volume (gal/ gm U^{235} consumed)*	*Approx. specific gravity*	*Approx. concentration of U in feed (gm/ liter)*	*Waste activity‡ (total watts/ gal§)*
Process	*H*	*Al*	*Fe*	*Cr*	*Ni*	*Zr*	*Na*		*Hg*	*NO_3*	*F*	*SO_4*				
Redox	−0.2	1.2					0.46			4.1			0.27	1.18	450	8.6
Purex	2.5–7									2.5–7			0.34	1.07	300	6.7
Thorex	−0.1	0.5							0.01	1.4	0.05		0.34	1.12	350(Th)	0.4
								NH_4								
Hexone-"25"	−0.2	1.5						0.5	0.01	4.5			0.31–0.13	1.23	2–5	8.1–20.2
TBP-"25"	0.5	1.6							0.01	5.5		0.02	0.22–0.11	1.29	3–6	12.9–26
Zirconium-KF								*Sn*								
for enriched U	0.8–2	0.8		0.1		0.5		0.02		2.3	3.0		~1.50	~1.1	0.3	1.75
Stainless steel-H_2SO_4 for								*Mn*								
enriched U	2.6	0.25	0.05	0.01	0.03			0.001		2.4		0.30	~0.35	~1.3	2–3	7.5

* Wastes are untreated; they are essentially as they leave the solvent extraction plant and are subject to further treatment such as evaporation, neutralization, chemical treatment for fission product removal, etc.

† Waste volume per gram U^{235} consumed is an inverse function of burnup, i.e., for hexone-25 at 20% burnup, the gal/gm U^{235} = (53/20)(0.14).

‡ Basis for activity numbers: irradiation period 4,000 Mwd/t for natural uranium, 5×10^{13} n/cm²/sec, 4,000 gm U^{233} chain per ton of thorium, 53% burn-up for U^{235} in enriched fuel elements, and 100-day decay cooling from time of reactor discharge. Waste activity varies approximately as the (irradiation level)$^{0.2}$; and indirectly with the concentration of fissionable or fertile material in the fuel.

§ After 100-day decay, the energy distribution is ~50% γ and 50% β.

Precipitation probably is finding its greatest use in the recovery of specific fission products or the scavenging of the fission products from the bulk wastes. A supernate can be sufficiently decontaminated to permit disposal to the environment under specific circumstances. The latter application has probably reached its greatest current refinement at Hanford (*2*). The specific geologic and hydrologic conditions there are the major factors contributing to its success.

In waste-scavenging operations, precipitates and *p*H control are utilized to remove the more hazardous radioactive materials from wastes prior to ground disposal. As practiced at Hanford, nickel ferrocyanide is used as a carrier precipitate to remove Cs^{137}, and inert calcium or strontium is added to aid in precipitating Sr^{90} as hydroxide and phosphate.

Although most of the metal ferro- and ferricyanides are effective cesium scavengers, nickel ferrocyanide is relatively cheap and performs well at *p*H 7–10. The substantial decontamination factors (300–1,000) obtained at *p*H below 10 abruptly decrease at higher *p*H.

Radiostrontium can be recovered from alkaline wastes with a wide variety of compounds. Since many wastes contain metal ions whose hydroxides and phosphates are insoluble, merely neutralizing these wastes effects considerable strontium decontamination. Additional strontium decontamination can be obtained with the further precipitation of insoluble materials. In particular, calcium and strontium phosphates are very effective scavengers for radiostrontium. Decontamination factors of 450 have been routinely achieved for Sr^{90}.

Plutonium chemistry is also characterized by relatively insoluble hydroxides, sulfates and phosphates. Thus, as in the case of strontium, neutralization results in appreciable decontamination.

The precipitate formed during scavenging operations is allowed to settle as a sludge in the underground storage tank. The supernate —~90% of the original volume of untreated wastes— is decanted to a ground-disposal facility where residual activity is removed by uptake on soils.

Typical plant-scavenging results are shown in Table 7.

The total cost of waste-scavenging activities, including the costs associated with ground disposal of the supernates, have averaged 5–6 cents/gal of storage space recovered. Approximately 1% of this was expended on waste-scavenging chemicals.

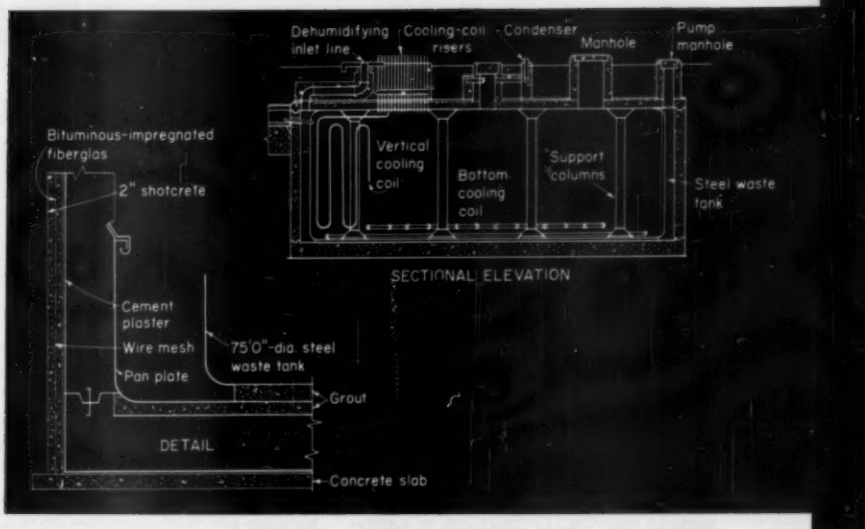


FIG. 2. Storage tanks at Savannah River Plant are similar to those at Hanford (Fig. 1) except for heat removal and construction details required by environmental conditions (ground-water proximity, population, etc.). Coils remove heat to keep waste below boiling point. Cup-and-saucer arrangement provides for leakage collection. Tank capacity is 750,000 gal

Ion-exchange. Ion-exchange techniques have also received some attention for treating high-level waste. The radiation damage to the resins must be considered. Continuous ion-exchange systems have been suggested to control the loss of ion-exchange capacity.

A scheme for treating aluminum-nitrate waste has been described (*6*). Waste solution is mixed with caustic to carry on ferric-hydroxide precipitate 99.9% of the rare earths, 99% of Sr, 75–90% of Zr, Nb and Ru but none of the Cs. If there is no iron in the waste, it is added. A 400-fold reduction in waste is expected. The Cs is separated from the precipitation supernate by cation exchange. Cs is eluted with HCl and evaporated. The decontaminated sodium aluminate is discarded or aluminum hydroxide can be precipitated with CO_2. If the waste does not contain aluminum, ammonium hydroxide is used instead of sodium hydroxide, and the waste from ion exchange after Cs removal can be treated with lime and the ammonia recovered by boiling. This scheme is currently under investigation.

Crystallization. Some work has been done (*2*) on the application of crystallization phenomena (i.e., the differences in solubility of aluminum nitrate in hot and cold 70% nitric acid) to aluminum nitrate wastes.

Such wastes were evaporated to 3.5*M* and decontaminated in three successive crystallization cycles. Decontamination factors were 10–60 for the first cycle and up to 2,000 after the third cycle. Recovery of aluminum nitrate was 80–95%.

Although concentration factors of 300–500 are indicated as possible from pilot-plant results, this appears to be optimistic.

Solid Preparation, Fixation

Because of the inherent limitations of tank storage as an ultimate-disposal system, many workers have pursued systems for converting high-level liquid wastes to a solid-oxide form or for fixing the radioactivity in an inert, nonleachable solid carrier.

Conversion to oxide. Conversion of aluminum-nitrate wastes (from aqueous processing of U-Al alloy fuels) to an oxide form has been studied at Argonne and Brookhaven National Laboratories and the Idaho Chemical Processing Plant.

At ANL and ICPP, a fluidized-bed technique has been utilized with nitrate conversion temperatures of 400–500° C (*7*). Pilot-plant work is presently

being carried out in a 2-ft-square (100 l/hr) unit recently completed at ICPP, and engineering design (by Fluor Corp.) of a prototype fluidized-bed plant is underway.

At BNL, a small-scale rotary-ball kiln has been used as the fluid-solid contactor. Nitrate-to-oxide conversion has been carried out at temperatures up to 950° C.

Hatch and his group at BNL have proposed a two-kiln unit for conversion to oxide. The first ball-kiln section would operate at about 650° F to evaporate the waste solution and decompose the nitrates in the powder. Metal balls would prevent agglomeration and would produce a free-flowing solid product. The second kiln unit, operating at about 1,300° F, would be used to convert the fluorides of aluminum and/or zirconium to oxide by hydrolysis.

Also at Brookhaven, Manowitz and Hittman have proposed calcination of aluminum-nitrate wastes in a screw-type calciner. A fluxing agent (sodium nitrate is present in these wastes) enables the production of a fused salt that is solid at room temperature and free-flowing at 300° C. Volume reductions of 3/1 over concentrated aqueous wastes are possible. It is proposed that the material be cast in convenient sizes or shapes to facilitate heat removal during storage.

One of the more important problems associated with the conversion-to-oxide schemes is that of control of highly radioactive particulate material during fluid-solid-contactor operation and during transportation and storage of the solid product. Workers at ICPP are giving detailed consideration to the off-gas and air-cleaning aspects of the fluidized-bed approach. Corrosion, remote maintenance and decay heat are also major considerations.

The solubility of some fission-product oxides is a disadvantage in ultimate storage. Careful selection of a geologic disposal site is one possible solution. Another approach involves leaching of the oxide product to remove the soluble radioactivity followed by fixing the leach solution in an inert solid. An advantage in this technique is the possible economic recovery of useful fission products.

Extensive leaching studies have been carried out at BNL. Work is now underway there on fixing the leach solution in montmorillonite clay.

At ICPP, Grimmett (7) has used pulsed-solvent extraction-column techniques in a unit in which solids and leaching liquid counterflow on a continuous basis. The unit also appears useful for ion-exchange systems.

Fixation in inert solids. Probably the earliest work on fixing radioactivity in stable, solid media was done by Hatch and co-workers with montmorillonite clay.

The initial mechanism in this scheme is ion exchange. The cation-exchange capacity of the clay is 1–1.5 milliequivalents/gm. Subsequent heating of the clay to about 1,000° C fixes the activity, apparently by collapsing or cementing the original plate-like crystal structure of the clay.

A pilot plant to demonstrate the feasibility of clay fixation has been operated at BNL. Present work involves investigating 15-ft clay columns to obtain high decontamination factors for Sr^{90} from leach solutions.

For effective clay fixation, bulk inert cations, e.g., aluminum and zirconium, must be separated from the fission-product ions in a pretreatment step. Where nitric acid is involved (Purex), its removal by volatilization and electrolysis with perm-selective ion-exchange membranes shows promise—reductions to $<0.08M$ have been obtained. Conversion to the oxides followed by leaching may also be considered for separating the inert from the active ions.

Struxness and co-workers at Oak Ridge are investigating a process of mixing high-level wastes with Conesauga shale, limestone and soda ash and allowing the decay heat to fix the activity in a ceramic mass at 600–900° C. Very high concentrations of radioactivity would be required to provide an initial heat evolution of several watts per gallon to self-sinter within reasonable times. With acid aluminum wastes, about 34,000 Btu/gal of finished cake are required.

Other workers are investigating similar fixation processes utilizing external heat sources. These involve the mineral nepheline syenite (Durham et al., Canada); a naturally occurring aluminosilicate earth material (Lower Greensand) and various glass formulations (Amphlett et al., England); naturally occurring clays (Christenson, Thomas, et al., Los Alamos); and synthetic mica (Cohen, France). In all of these processes, wastes mixed with powders or slurries of the carrier mate-

TABLE 3 — Accumulation and Decay of Fission Products

Nuclide	*Half-life* (*yr*)	*Accumulation** (*μc/ml*)	*Residual†* (*μc/ml*)	*0.1 MPC‡* (*μc/ml*)
Sr^{89}	0.148	21.1×10^4	¶	7×10^{-6}
Sr^{90}	28	3.0×10^4	2.3×10^4	8×10^{-8}
Y^{91}	0.159	26.4×10^4	¶	2×10^{-2}
Zr^{95}	0.178	30.0×10^4	¶	
Nb^{95}	0.096	30.0×10^4	¶	4×10^{-4}
Ru^{103}	0.110	13.6×10^4	¶	
Ru^{106}	1.0	1.4×10^4	14	10^{-2}
Te^{129}	0.090	1.6×10^4	¶	10^{-3}
Cs^{137}	30	2.5×10^4	2.0×10^4	1.5×10^{-1}
Ba^{140}	0.035	30.0×10^4	¶	2×10^{-4}
Ce^{141}	0.088	28.2×10^4	¶	
Pr^{143}	0.038	28.2×10^4	¶	4×10^{-2}
Ce^{144}	0.780	24.7×10^4	35	4×10^{-3}
Nd^{147}	0.032	12.2×10^4	¶	
Pm^{147}	2.6	6.9×10^4	4.8×10^4	0.1
Sm^{151}	80	0.005×10^4	49	0.02
Pu§	2×10^4	3	3.0	1.5×10^{-7}
U§	7×10^8	5.3×10^{-3}	5×10^{-3}	7×10^{-4}

* Accumulation in ten years by power program starting at 2,000 Mw and increasing to 30,000 Mw. Expressed as microcuries per milliliter assuming a waste volume 1.5×10^6 gallons.

† Microcuries per milliliter after an additional ten-year decay of the ten-year accumulation.

‡ Ten per cent of Handbook 52 maximum-permissible values for concentration in water.

§ Assuming 1% losses for arbitrary operating conditions.

¶ Less than 0.1 MPC.

TABLE 4 — Capital Costs of Radioactive-Waste Storage Tanks

Installation	*Capacity (gal)*	*Year constructed*	*Material of construction*	*Internal cooling provided*	*Reflux condensers*	*Total cost ($)*	*Cost ($/gal)*	*Comments*
Site A high-level waste	600,000	1952–54	Carbon steel	Yes	Yes	Avg. 1,080,000	1.80	Neutralized waste only
Site B high-level waste	1,000,000	1954–55	Carbon steel, concrete	No	Yes	Avg. 403,000	0.40	Neutralized waste only
high-level waste (estimates)	1,000,000	Bids 1954	Carbon steel, concrete	No	Yes	172,000	0.17	
Hanford, hot semi-works	30,000	1951–52	Stainless-steel liner	No		83,090	2.77	
CPP, high-level waste	318,000	1951–52	Stainless steel, concrete	No	Yes	546,415	1.77	Stores acid raffinates
CPP, high-level waste	300,000	1954–55	Stainless steel, concrete	Yes	Yes	869,390	2.80	Stores acid raffinates
CPP, high-level special interim	30,700	1954–55	316 stainless steel	Yes	Yes	255,000	8.20	Interim storage of acid fluoride and sulfate wastes
Hope pit for intermediate level	5,000,000	1954	Asphalt lining in earth pit	No	No	700,000	0.14	Not in use; still being studied

rial are heated to 800–1,300° C. Fluxing agents, such as sodium nitrate or sodium carbonate, are also used.

The advantage of such systems is that they are not specifically dependent upon ion-exchange capacity and therefore are not confronted with the problem of interference of inert constituents. Also, they approach what appears to be the most nonleachable form of such materials—waste constituents chemically incorporated in the crystal structure of highly inert materials.

The latter has led to the proposal by Patrick (Johns Hopkins) to fix wastes in synthetic feldspars. Since the feldspar form of the alkaline-earth metals is highly insoluble, nuclides such as strontium or cesium in the feldspar form would represent an optimum disposal form. The product of a conversion-to-oxide plant is dissolved in caustic to form a sodium aluminate (in the case of an aluminum-bearing waste), mixed with sodium silicate to form a hydrogel, and then dried and fired to form a feldspathic mineral of the type $M_2O \cdot Al_2O_3 \cdot 4SiO_2$. To get the crystalline structure, 80% of the stoichiometric amount of caustic is used in forming the sodium aluminate and 20% of the sodium is removed from the sodium silicate by ion-exchange. With zirconium-bearing wastes, colloidal silica is added to nitric-acid waste solutions to form a gel. Drying and firing form a crystalline structure equivalent to zircon, $ZrSiO_4$.

At MIT, the group under Eliassen is studying the improvement of the insolubility characteristics of fired waste oxides by the addition of vitrifying or glazing agents. Glaze formulations of the type Al_2O_3-CaO-SiO_2 and Al_2O_3-CaO-SiO_2-borax with fusion temperatures up to 1,250° C have been investigated.

In all of the fixation processes where relatively high-temperature firing steps are involved, problems associated with volatilization of certain nuclides (cesium for example), control of ruthenium and active aerosols and others (such as corrosion) have yet to be solved. In fact, engineering development and pilot-plant operation have yet to be done for the most part.

Ultimate Disposal

Compared to the research and development effort directed toward waste *treatment*, very little has been done in the direction of "engineering" ultimate disposal systems.

Although developmental work in this area is just getting underway, there has been very useful analytical consideration of the problem. Certain tentative conclusions can be made:

1. The possibility of safely dispersing large quantities of radioactivity in the environment is remote. Besides, other nondispersing, "contain and control" systems appear to be preferable from both the hazard and engineering standpoints.

2. Possibilities appear to exist in certain geologic environments for the permanent deposition of aqueous or, preferably, solidified wastes.

3. Much research remains to be done before even developmental field-scale experiments can be performed.

Land disposal. Preliminary evaluations (*8*, *9*) indicate the technical feasibility of direct disposal of high-level wastes into specific geologic formations. It *may* be practical ultimately to dispose of the wastes (possibly without pretreatment) into such formations as:

1. Spaces prepared by dissolution or mining in salt domes or salt beds.

2. Deep, isolated synclinal basins (4,000–15,000 ft deep) containing connate brines.

3. Excavations in shale formations.

4. Porous formations, e.g., sandstone.

In addition, the possibility of using the "hydrofrac" technique of secondary petroleum recovery in certain geological formations has also been suggested.

The two major problems associated with such direct disposal schemes appear to be (a) the physical and chemical compatibility of the wastes and the geologic-formation material and (b) control of thermal heat due to radioactive decay. Recent calculations and

analytical work at ORNL and the University of Texas tend to reduce the supposed severity of the thermal-heat situation, but quantitative conclusions remain for the future.

Disposal into salt structures appears, at the present time, to be the best possibility. Substantial salt deposits are fairly well distributed in this country. Considerably more salt is mined annually than the expected future production of high-level wastes. Also, in recent years, considerable experience has been accumulated by the gas-storage industry in constructing, by dissolution processes, storage cavities of hundreds of thousands of gallons capacity. Salt structures represent a particularly uniform geologic environment and are dry, impervious to water and not associated with useable ground-water sources. They behave as plastics under load and may, therefore, be considered a kind of "self-sealing" storage tank. Heroy (*8*) has made a preliminary study of salt formations for this purpose. Gloyna (U. of Texas) has carried out a number of laboratory experiments related primarily to structural stability of salt cavities. He has also calculated heat generation and its effects.

TABLE 5 — Evaporator and De-entrainer Performance

Unit	*Vapor-filtration, vapor-compression cyclone separator*	*Forced-circulation, flash-type, 4 bubble-cap trays*	*Double effect with reflux*
Boilup (lb/hr/ft²)	87		20
Decontamination factor (pot to condensate)	6×10^7	$\sim 10^7$	5.5×10^8
Volume-reduction factor	33	350	
Concentrate (% solids)	60	70	0.2

For deep-well disposal it appears likely that considerable pretreatment (e.g., dilution, complexing agents) will be required to prevent plugging of the receiving formation. Plugging might also be eliminated by hydraulic fracturing of the formation. However, the migration of the radioactive materials must be controlled.

In the case of "abandoned oil wells," the waste would be denser than the saline water normally contained in oil-bearing beds (provided the decay heat does not produce convection currents). Instead of concentrating in the tops of anticlines, the waste would tend to sink to the bottoms of synclines. Also, with the development of new and improved methods for secondary recovery of petroleum products, it becomes increasingly difficult to define what is meant by "abandoned" oil well.

It has been noted that the removal of cesium and strontium might be another approach to the thermal problem. Decontamination factors required in this case would be substantially smaller than those required if the remaining wastes were to be dispersed into the environment. Also involved are chromatographic effects or selective adsorption or concentration of radioactivity in the formation material. In general, it appears that the details of heat generation and dissipation can only be quantitatively defined through prototype field experiments.

Ocean disposal. Oceanographers

TABLE 6 — Summary of Selected Waste-Evaporation Costs

Unit	*Estimate date or year built*	*Approximate activity level*	*Nominal capacity*	*Installation cost ($)*	*Operating costs ($/gal)**	*Approximate total cost ($/gal)**	*Reference*
Oak Ridge National Laboratory	1949	10^6–10^8 d/min/ml 2 years or older	300 gal/hr as condensate	45,000 building 45,000 equipment	0.054	0.06	ORNL-1513
Idaho Chemical Plant	1952	10^7–10^9 d/min/ml 120 days cooled	350 gal/hr as condensate	450,000 equipment 300,600 building	0.149	0.179	W. G. Stockdale
Mound Lab high-level solvent-extraction raffinates (estimate)	1952	a. Highly salted full level feed b. " "	a. 100 gal/hr as feed b. 1,000 gal/hr as feed	a. 200,000 building 200,000 equipment b. 800,000 building 800,000 equipment	a. 0.169 b. 0.037	0.253 0.069	MLM-672 " "
Westinghouse Atomic Power Division low-level concentration		Very low	1,600,000 gal/yr as condensate†	43,000 building 71,100 equipment	0.023	0.035	(*13*)
Brookhaven low-level evaporator	1952	Low level	367,000 gal/yr as feed†	92,900 building 204,400 equipment	0.033	0.17	(*13*)
Knolls Atomic Power Laboratory low-level wastes	1950	Low level	4,500 gal/day as feed†	324,000 building 570,000 equipment	0.025	0.156	(*13*)

* Includes amortization: 10 yr for building, 5 yr for equipment, 300 days/yr.
† Actual processing rate rather than nominal capacity.

TABLE 7 — Typical Plant Scavenging Results*

Scavenging agent	Decontamination factor: Cesium	Decontamination factor: Strontium
0.0025*M* $Ni_2Fe(CN)_6$	200–1,000	50–150
0.0025*M* $Ni_2Fe(CN)_6$ + 0.03*M* $Ca(NO_3)_2$	200–1,000	100–300
0.0025*M* $Ni_2Fe(CN)_6$ + 0.004*M* $Sr(NO_3)_2$	400–1,000	250–700

* Aqueous waste originally contained 0.2*M* phosphate, 20–80 μc/ml cesium and 30–100 μc/ml strontium.

have pointed out that the dilution or diffusion mechanisms in large masses of the ocean are quantitatively unpredictable. In addition, the degree of reconcentration of radioactivity in marine life and the long-term ecological implications are uncertain. These uncertainties, considered with handling and transportation problems, lead to a discouraging picture of large-scale ocean disposal. Craig (*10*) concludes that on a theoretical basis the wastes of a predicted nuclear power economy can be safely assimilated by the sea. However, he does not consider the engineering problems. An important factor to consider is the complete loss of control of the waste once it is disposed. In view of the long-term implications, the preference for nondispersing systems is strengthened.

Other Considerations

There are ancillary problems in ultimate disposal that must be included in an over-all evaluation. These include economics of optimum waste-storage time versus shipping distance to a disposal point (*3*, *5*) and the location of chemical reprocessing plants with respect to reactors that they service and suitable waste-disposal sites.

In turn, administrative problems are introduced by such factors as transport. Since very little operating experience is available, many questions regarding the regulatory, hazard-control and emergency requirements for shipment of large quantities of radioactive materials remain to be specifically answered.

Removal of specific fission products. Separating out specific isotopes, particularly Sr^{90} and Cs^{137}, would facilitate the disposal of high-level liquid wastes. Work being done on the recovery of useful fission products from waste streams has been noted previously.

The important point to be made here is the distinction between the *recovery* of specific fission products for whatever useful purpose and the *removal* of specific fission products as a waste-disposal technique. Processes for accomplishing the former are presently available and in use. Processes for accomplishing the latter are still in the early stages of development.

Pyrometallurgical and volatility process wastes. In general, the state of process development in pyrometallurgical and volatility nuclear-fuel reprocessing is not sufficient to describe in detail the fission-product wastes that will be associated with these process schemes.

As Anderson has noted in the previous article in this series (NU, Dec. '57), the salt residues of the volatility process are in the desired direction of high-level-waste solidification in inert carriers. The same generally holds true for pyrometallurgical and other low-decontamination-factor processing systems. However, although the fission products may be more concentrated in the waste streams coming from these systems, they still do not solve the ultimate-disposal problem. The waste problems associated with these processes differ in degree but not in kind from those involved in present aqueous processes.

Gaseous wastes. From the standpoint of waste control during reactor and processing-plant operation, I^{131} is by far the most significant of the gaseous fission-product wastes. From a long-term standpoint, other important gaseous wastes are krypton and to a much lesser extent I^{129}.

Continuous iodine removal from gaseous-waste streams has been developed to a degree satisfactory for processing fuels that have been cooled for 60–120 days and for processing plants in present relatively isolated areas. Complete iodine removal or the control of iodine when processing short-time-cooled fuel elements remains to be developed.

Highly contaminated particulates or aerosols are produced in chemical reprocessing, particularly by alpha-active materials (*11*). Control systems, including high-efficiency filters and deep-bed fiber units, have been developed. Silverman (*12*) and Schmidt (*2*) have described these systems in detail. For example, high-efficiency filters are capable of collecting 99.5% of particles 0.3 microns in diameter. At the present time, such filtration is somewhat limited to temperatures below 500–600° F. Filtration at higher temperatures requires further development work, although ceramic fibers of 50% Al_2O_3 and 50% SiO_2 (Fiberfrax) are promising.

* * *

In addition to the references cited below, the author has made extensive use of the following sources: Symposium on the Reprocessing of Irradiated Fuels, Brussels, May '57, (published by the AEC as TID-7534); ORNL CF-57-3-114 (Rev.), the initial draft of a report to be published by the Committee on Disposal and Dispersal of Radioactive Wastes of the National Academy of Sciences—National Research Council; report of a special committee of the Division of Earth Sciences of the NAS-NRC; minutes of the meeting on fixation of radioactive materials held at The Johns Hopkins University (1957).

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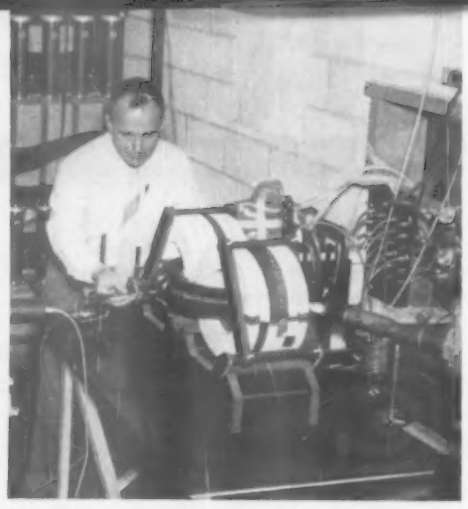
COLUMBUS II is a linear discharge device fed by 25 low-inductance condensers located in a circle around it



PERHAPSATRON S-3, small toroidal apparatus, has reached 5×10^6 °K

The wraps come off these pinch-effect devices as . . .

United States and Britain

The declassification of certain data on controlled thermonuclear power last month by the U. S. Atomic Energy Commission and the U. K. Atomic Energy Authority brought to a conclusion another phase in the short but strange history of this new technology. With its short-term prospects exaggerated through ignorance born of the cloak of secrecy in which it has been wrapped, fusion work has now been forced partly out into the open by political considerations. The picture revealed is one of a field still very much in its infancy.

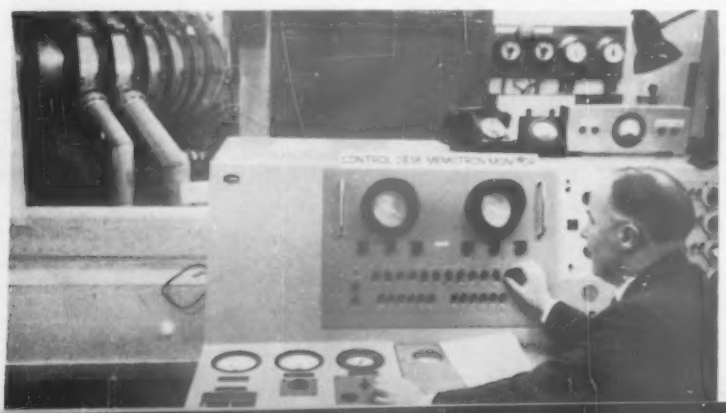
Although research on fusion power goes back to 1952, public acknowledgment of its existence did not come until the 1955 atoms-for-peace conference when Homi Bhabha's prediction of its eventual achievement was followed by revelation by the U. S., U. K. and U. S. S. R. that they had programs in the field.

Nothing very much more was said until the Russians scored a propaganda triumph when Igor Kurchatov delivered his now-famous lecture at Harwell in April, 1956, on Soviet pinch-effect experiments (NU, June '56, p. 36). Later that year, at a Stockholm conference, the Russians revealed further details of their work.

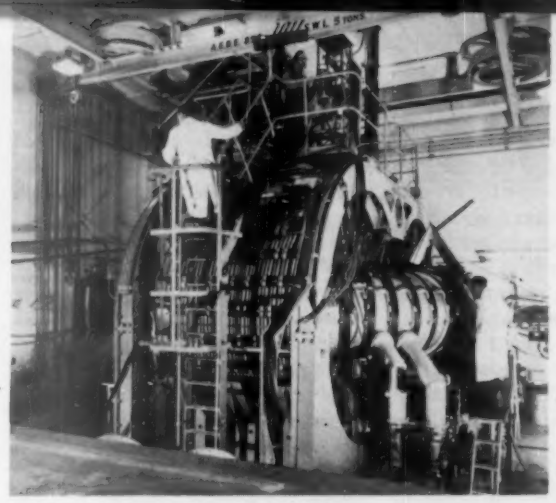
Meanwhile, the U. S. and the U. K. were struggling, first, to work out an agreement on the sharing of fusion data and, second, to determine what, if anything, should be declassified on the subject.

The eight papers released simultaneously on Jan. 24 by the U. S. and the U. K., and reported on here, represent the first substantial Western declassification of data. They make clear that no scientific breakthrough has been achieved. Rather they indicate that steady progress is being made—plasmas have been confined for short periods of time and temperatures sufficient to produce thermonuclear neutrons approached.

CONTROL ROOM for ZETA (Zero Energy Thermonuclear Assembly)



GLASS TORUS of Perhapsatron S-3



ZETA is much larger than U. S. machines; aluminum discharge tube has 1-meter bore

PINCH EFFECT DEVICES UNVEILED

Device	*Laboratory*	*Geometry*	*Typical D_2 pressure (μ)*	*Pinch current (ka)*
ZETA	Harwell	Toroidal	0.25	150
SCEPTRE-II	AEI, Ltd.	Toroidal	0.5	200
Columbus-II	Los Alamos	Linear	100	1,000
Columbus S4	Los Alamos	Linear	40	250
Perhapsatron S-3	Los Alamos	Toroidal	>30	200

Reveal Fusion Advances

THOUGH THERE IS still no certainty that a power-producing thermonuclear reactor can be built, prospects seem brighter as a result of last month's declassification of pinch-effect research in Britain and the U. S. (Condensed versions of the scientific reports are given at the end of this article.) Not only have temperatures of 3–6-million degrees been achieved but the totally ionized plasma has been stabilized and successfully confined for times that range as high as 5 milliseconds. This is still far from the 400-million-degree temperatures and few-seconds pinch duration required for power production, but gives grounds for optimism.

Pinch-Effect Devices

While the papers say nothing about the several other approaches to thermonuclear power that are being pursued in the U. S., the disclosures are regarding the pinch effect quite complete and cover experiments up to December, 1957. Unveiled are such devices as Los Alamos' Columbus I and S-4, and Perhapsatron S-3 as well as Harwell's ZETA (Zero Energy Thermonuclear Apparatus). Basically all the devices employ a high-current discharge through low-pressure highly-purified deuterium gas to produce the contraction and consequent heating that is the pinch effect. In this respect they are like earlier pinch effect devices (*1–5*). The something new that has been added is the use of longitudinal magnetic fields to stabilize the pinch. This principle has been hinted at (*6*) as the next step in pinch-effect research but not revealed before this.

The British papers describe two large toroidal machines of which ZETA is the more important. It is built on a much larger scale than the American toroidal pinch device Perhapsatron S-3. For example, the bore of the British torus is 1 meter while that of the American pinch machine is 5.3 cm.

Neutron Production

All the machines described (*7–13*) have produced neutrons from fusion reactions. In particular ZETA and Perhapsatron S-3 have both produced about 10^6 neutrons per discharge. At first this seems surprising in light of the striking size difference between the two devices, but it can be explained. The British chose to operate at lower pressure than the Americans (10^{-4} mm Hg as opposed to 10^{-3} mm). Now the reaction rate per unit volume is given by $\frac{1}{2}n^2(\sigma v)_{avg}$, where n is the density of duterons and $(\sigma v)_{avg}$ is the average of the reaction probability over the Maxwellian distribution of velocities, a function of temperature only (*14*). Since both ZETA and Perhapsatron S-3 have achieved comparable temperatures, $(\sigma v)_{avg}$ is the same for both machines. This means that the Los Alamos device, with its 100% greater pressure will produce neutrons at 10,000× the rate per unit volume, enough to compensate the much greater volume and confinement time of the British machine.

However, in spite of some impressive evidence there seems to be residual uncertainty as to whether these neutrons are truly thermonuclear.

To be truly thermonuclear the neutrons should be the product of fusion reactions between deuterium moving at random in the heated plasma. Unfortunately, it is also possible to have neutrons produced by deuterons moving in a directed fashion as the result of acceleration mechanisms that are associated with the pinch effect. Such false neutrons have been observed by most groups doing pinch-effect research, usually as a result of acceleration mechanisms associated with instabilities in the pinch. Thus it is significant to have a device that produces thermonuclear neutrons if only because its additional evidence that the machine is stable. More importantly thermonuclear neutrons would, by definition, be evidence that the discharge was in approximate temperature equilibrium. One can then hope to extrapolate to higher temperatures by appropriate scaling laws.

The evidence that the neutrons from

the devices just unveiled are thermonuclear is principally the fact that the numbers of neutrons agree with what would be expected theoretically from a plasma at a temperature that is given by other measurements principally spectroscopic and magnetic. However, the neutron fluxes have been insufficient to permit the one clinching experiment, namely, the measurement of the energy spectrum of the neutrons to determine whether they are in fact created by deuterons moving at random.

As if to point up the need for caution in this regard the release of information includes a paper from S. Colgate's group at Livermore in which there is related the results of a pinch-effect experiment with a linear device in which several types of evidence pointed to thermonuclear origin for the observed neutrons. However the crucial measurements of neutron spectrum using photographic plates showed that the neutrons were due to accelerating mechanism. Colgate concludes that "the denial of the optimistic conclusion of a thermonuclear yield despite so many favorable results was indeed a sobering experience. . . . It is therefore tentatively suggested that a thermonuclear yield cannot be proven by simply a large number of corroborating neutron measurements but instead must in addition be in agreement with a basic understanding and with measurements of the plasma physics."

By Colgate's criterion one is forced to conclude that the neutrons observed in the newly declassified experiments are not certainly thermonuclear, though they might be.

Spitzer's Paper

An interesting light is cast on the whole series of thermonuclear devices here reported by a simultaneously released paper by Lyman Spitzer, Jr., head of thermonuclear research at Princeton University's Project Matterhorn. Spitzer points out that "electron-ion collisions are inadequate to explain the observed rate of heating, and some unknown mechanism would appear to be involved." In particular in ZETA temperatures of 3.3×10^6 °K

An Editorial

The Perils of Secrecy

One of the most humiliating examples of the harm that secrecy can do came last month on the occasion of the simultaneous release of fusion data by the United States and the United Kingdom. It was demonstrated very dramatically that scientific research that has great potential for peacetime application can't be bottled up by classification with the expectation that undistorted, unpressured, normal scientific activities can still be carried out.

Instead there is a spiraling buildup of false hopes among outsiders, technical and nontechnical, and even among insiders, about the significance of every bit of progress made along the way. Those working on the project feel these pressures and frequently find themselves striving for unrealistic goals.

This was what happened in the field of thermonucleonics.

Work on fusion was originally classified for two reasons: military and, reportedly, economic. In the latter case, some felt that a tremendous new economic force might be produced and that we would not tip our hands to others.

In the military justification, it was stated by AEC that "it appears that any thermonuclear reactor will be a substantial neutron producer capable of producing substantial quantities of special nuclear material."

Now—last month—a first step in declassification of fusion data has been taken that essentially says that the economic argument for secrecy no longer makes sense because of the long-term nature of the development. And also that there is less reason for the military argument, which is borne out by the fact that the information released gave great emphasis and details on the production of neutrons.

In the meantime, however, harm has been done to the program and to the morale of scientists working in it. The Americans suddenly found themselves thrust into a situation where they were overtly competing with the British. The Harwell team had last summer produced what it thought might be thermonuclear neutrons. The scientists had the desire to publish their results. At least some Americans felt that if there was to be any publication the U. S. should have thermonuclear neutrons to talk about also. And so the rush was on to do just this.

While this behind-the-scenes race was going on, the impression became current that the British had achieved a major scientific breakthrough.

Then came the anticlimactic bilateral announcement last month that both countries *thought* they had produced thermonuclear neutrons. Although very impressive and important scientific work has been done on both sides of the Atlantic, there is real doubt that any milestone has been achieved that will go down in history as has the discovery of fission and the development of the first selfsustaining chain reaction. Nor is there even any evidence that the development of a thermonuclear reactor is assured.

Although the scientific papers released clearly show that neither the U. S. nor the U. K. is further advanced than the other, one thing that is clear is that the spectacle that both teams have just gone through—the scientists, the administrators and the policymakers—was a humiliating and disconcerting one, one that needn't have been except for the secrecy that covered the work. Were it not for secrecy, presumably the work would have been reported on in a normal manner in scientific circles as other science is, and there would have been no psychological buildup to the point where an "event" had to be created as an occasion for the release of data.

Unfortunately, the U. S. may not be seeing the lesson inherent in the present situation and may be building up to another letdown at the Geneva conference later this year. Apparently, considerable additional fusion data is being withheld for Geneva with the hope of making great impact there. Once again, the scientists must "produce."

Whenever we engage in scientific olympic games of this type, we can't help but inflict requirements upon ourselves that may hurt us more than they help us. Science should be conducted in an atmosphere of free and open inquiry and results should be reported as normal progress warrants.—J.D.L.

were reached in 1 msec whereas theory (*15*) would require 4 msec at least. Spitzer concludes that "there does not appear to be any simple model, based on a quiescent plasma, which is consistent with the observed rapid heating of the positive ions." He suggests the possibility that cooperative phenomena, such as oscillations in the plasma sheath, may provide an explanation and calls for further investigation of such effects.

Conceivably such more fundamental study of pinch phenomena would provide insights that would point the way to successful power-producing machines, but it is also possible that it would reveal that present designs could not be extrapolated to power-producing size. Researchers in the field must weigh the merits of stopping to gain further understanding of the devices built thus far or forging ahead to larger devices that might prove successful even though incompletely understood.

Where To From Here?

The pinch-effect experiments just unveiled do not permit any definite conclusion as to the likelihood of eventual success in producing economic power this way. One of the Britons who worked on ZETA warned that "ZETA was a trivial development compared with that of devising a system in which there is a net power yield. Much more optimistic was T. E. Allibone who heads the Associated Electric Industries fusion team; he stated that "the hydrogen fusion process will become sound engineering practice in ten years." On the other hand top American officials still claim there was no reason to sell uranium short.

Certainly the experiments reveal that thermonuclear instrument experimentation is complex and difficult. Typical is the situation with respect to the thin (3-mm wall) glass torus of the Perhapsatron S-3 which must withstand the mechanical strains that can be transmitted to it from the heavy primary under electromagnetic forces.

Nonetheless, fusion researchers confidently expect to be making further progress in the months and years ahead. Harwell researchers are making improvements in ZETA's torus liner that will enable them to employ even higher pinch currents. Temperatures of 25×10^6 °K should then be possible. Los Alamos has similar plans for higher temperatures and neutron intensities and is readying other still-secret pinch devices. And it was also revealed that Princeton's Model C Stellarator will achieve 50×10^6 °K after its completion, now advanced to 1960.

Detailed Descriptions of Pinch-Effect Devices

What follows are condensed versions of the descriptions of thermonuclear devices and experiments as released by the U. S. AEC and U. K. AEA on January 24, 1958. References are to bibliography on p. 155.

Columbus—II (7)

The Los Alamos device known as Columbus II (July 1957) was designed as a high-powered machine in which the current reached its maximum value in as short a time as possible. By this means one could cause a pinch in times short compared with the growth of instabilities.

Description. The main condenser bank (p. 90) consists of twenty-five 0.8-μfd, 100-kv low-inductance condensers placed on the periphery of a circle 14 ft in diameter. The transmission line that connects the condensers to the centrally located linear discharge tube consists of two circular copper sheets separated by ½ in. of polyethylene. This bank is switched by a graded vacuum spark gap, which is located above the discharge tube. The condenser bank is charged by a Marx generator in 90 μsec. The inductance external to the discharge tube is 0.035 μh which implies that, under short-circuit conditions at 100 kv, the maximum current capability is 2.5-million amp. Typical operation is at 60 kv with a gas current of 1-million amp and a rise time of 2 μsec.

In addition to the main high-voltage bank, a second low-voltage bank (60 μfd, 20 kv) was available and could be used to form a partially stabilized pinch in the discharge tube before application of the high-voltage bank. The reason for this two-stage operation was the hope that the low-power pinch could be adiabatically compressed by the high-power bank beyond the region of stability to a high transient temperature.

Axial magnetic fields up to 10 kilogauss were provided by an auxiliary low-voltage condenser bank. Ceramic discharge tubes (30 cm long, 10 cm in diameter) of sillimanite were found to allow operation up to 55 to 60 kv. An interesting difficulty has until now prevented all effective use of the machine above 60 kv. The pinch phenomena can be identified by characteristic voltage or, in the case of extremely low-inductance supply, such as this one, current fluctuations observed during the discharge cycle. These are found to disappear at voltages above 55 kv as do the neutrons.

Results. Using the low-voltage (preheater) bank alone neutrons were produced in short bursts (0.1–0.3 μsec long) occurring approximately at the time of the first and second contraction of the pinch. The maximum yield of neutrons was 2×10^7; the yield decreased by a factor of 6 by the addition of a 23-gauss axial magnetic field which suggests that these neutrons may be produced by some instability mechanism.

With high-voltage bank alone the neutrons appear shortly after the first contraction, as indicated by the small dip in the current. With no axial (B_z) magnetic field a short (0.3-μsec) neutron burst with little or no tail is observed. A small B_z field lowers the relative height of the initial burst of neutrons and enhances the number of neutrons appearing in the tail of the neutron pulse. Neutron pulse durations of up to 1.5 μsec were observed with B_z fields as small as 200 gauss. The total yield of neutrons was rather insensitive to the axial magnetic field, dropping by only 55 per cent when the field was changed from 0 to 125 gauss. The

continued on p. 151

Stellarator Clue?

Buried away in the theoretical paper by Spitzer (*11*) that forms part of the newly declassified fusion material is a description of an experiment performed by T. Stix at Project Matterhorn. Since Matterhorn is currently designing a thermonuclear device known as the Stellarator, Stix' device may bear some relation to it. Here is how Spitzer describes Stix' device:

A discharge was produced in helium gas in a stainless-steel racetrack tube of 10 cm diameter and 240 cm axial length, with an initial pressure of 0.63 μ and an externally produced axial field of 19,000 gauss. The magnetic field was arranged so that intersection of the outer lines of force with material walls restricted the discharge to a channel of 5 cm diameter. A loop voltage of 300 volts was applied around an iron transformer threading the racetrack, and a maximum current of 8,000 amp observed; since this current produces only a minor perturbation in the magnetic field, there was no pinching of the discharge. Time-resolved spectroscopic profiles of the He II line, λ = 4,686°, indicated that the kinetic temperature of these ions increased to 1.2×10^6 °K in 1.5×10^{-4} sec, as compared to a theoretical maximum value of 0.8×10^8 degrees in this same time interval.

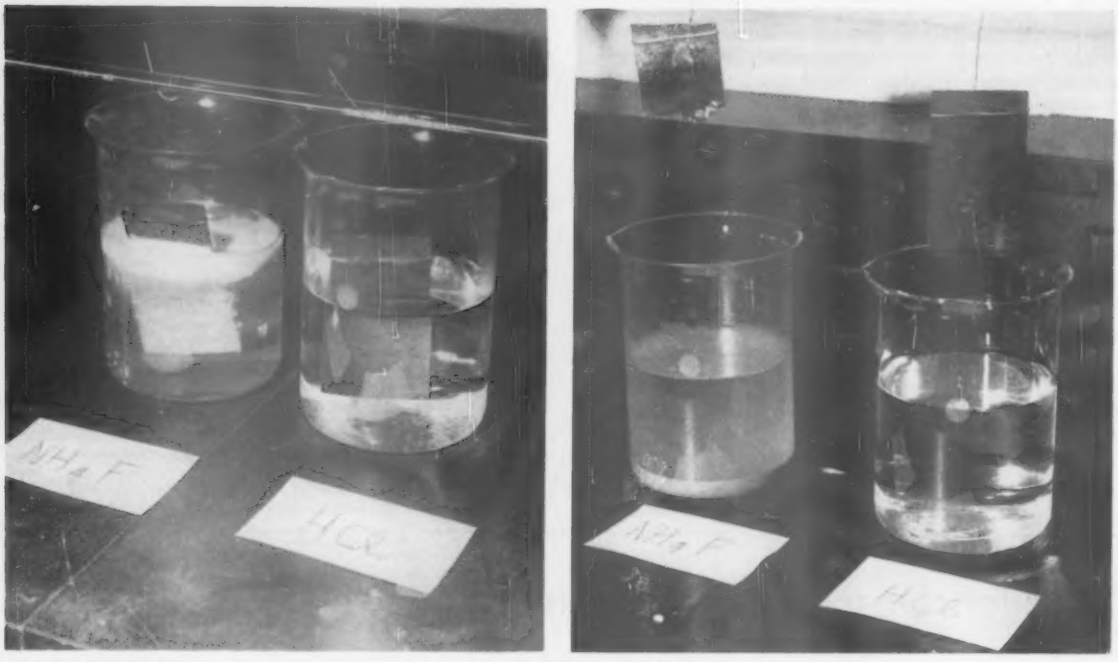


FIG. 1. Comparison of solution rates of zirconium NH_4F and in 6N HCl. At right are samples after reaction

NH_4F—Versatile Reagent for Zirconium Fuels

By A. T. McCORD and D. R. SPINK
Carborundum Metals Company, Inc., Division of the Carborundum Company, Akron, New York

Zirconium, although useful as a reactor material with its good corrosion properties and low thermal-neutron-capture cross section, presents some problems: scrap recovery is difficult because of oxygen and nitrogen absorption and resulting increased hardness; present plans for processing Zr-containing fuels envisage using difficult-to-handle hydrofluoric acid. Ammonium fluoride promises to ameliorate these problems as well as to offer other benefits for zirconium fuels.

A number of years ago, ammonium fluoride was used in a 10-ton/day plant to produce titanium dioxide from ilmenite. The operation was discontinued because the oxide was produced at 25¢/lb when the market price was 18¢/lb. We have now demonstrated that the complexing ability of ammonium fluoride is useful for the dissolution and treatment of zirconium and its alloys and its separation from uranium and the fission products. Used in the neutral and even acidic states, it would be far easier to handle and probably more economic than currently used reagents.

In addition to applications to the recovery of oxygen- and nitrogen-free zirconium scrap and decladding and separation operations of fuel reprocessing, an electrolytic procedure using ammonium fluoride has been found to improve zirconium and Zircaloy corrosion properties.

Scrap Recovery

Zirconium fabrication results in the generation of considerable scrap in the form of lathe turnings, mill chips and clippings. Some of the heavier scrap is reusable in the melting of ingots. However, in general, the turnings and chips have absorbed sufficient oxygen and nitrogen to increase their hardness considerably and make them unsuitable for reuse.

About 1954, attempts to recover such scrap were made by the Bureau of Mines* by etching away the oxygen- and nitrogen-bearing surface of the scrap with a nitric-hydrofluoric-acid mixture. Although the contaminated surfaces were removed, an insoluble oxygen-containing zirconium compound was deposited in the minute fis-

* Northwest Electrodevelopment Laboratory, Bureau of Mines, Albany, Oregon. Zirconium Progress Reports BM II-70 (June 15–July 15, 1953), BM II-72 (July 15–Aug. 15, 1953), BM II-80 (Sept. 15–Dec. 15, 1953).

experience

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sures in the residual metal and could not be removed. This material invariably produced hard metal when the scrap was arc-melted.

We thought that this trouble could be circumvented by using an acidic ammonium fluoride solution—or ammonium bifluoride—because it was known that the complex $(NH_4)_2ZrF_6$ was quite soluble. Tests showed that such metals as titanium, zirconium, hafnium, the Zircaloys, uranium and thorium were not only soluble in acidic solutions of ammonium fluoride, but in neutral solutions also. Because of obvious advantages, all further investigations were made with neutral solutions in iron, rubber-lined or plastic containers.

The solution rate differs for the various metals, but increases with temperature and concentration. In some cases, at the higher temperatures and concentrations, the action is catastrophic. Figure 1 compares the reaction of zirconium with NH_4F to that with 6*N* HCl. Typical solution rates are shown in Fig. 2.

The reaction is probably quite involved, but the end results may be described by

$$M + XNH_4F = MF_4 \cdot YNH_4F + 2H_2 + 4NH_3$$

where M = Zr, Hf, Ti, U or Th, Y = an integer 2 or more and $X = Y + 4$.

As the gases leave the system almost quantitatively, the liquid maintains its original state of acidity, i.e., the *p*H remains constant and the dissolution rate is maintained.

At temperatures above 60° C, solutions of ammonium fluoride evolve appreciable quantities of ammonia and become more acidic according to the equation

$$(NH_4F)_2 = NH_4HF_2 + NH_3$$

However, the solution is strongly buffered and although the titratable acid increases, the *p*H changes only slowly. Thus even in strong, hot solutions the *p*H rarely goes below 5.

Experiments have shown beyond doubt that the oxide-nitride surface of zirconium and Zircaloy turnings and chips can be successfully removed in an ammonium-fluoride bath. No insoluble zirconium salts are formed, and the treated scrap is pure enough to be reused.

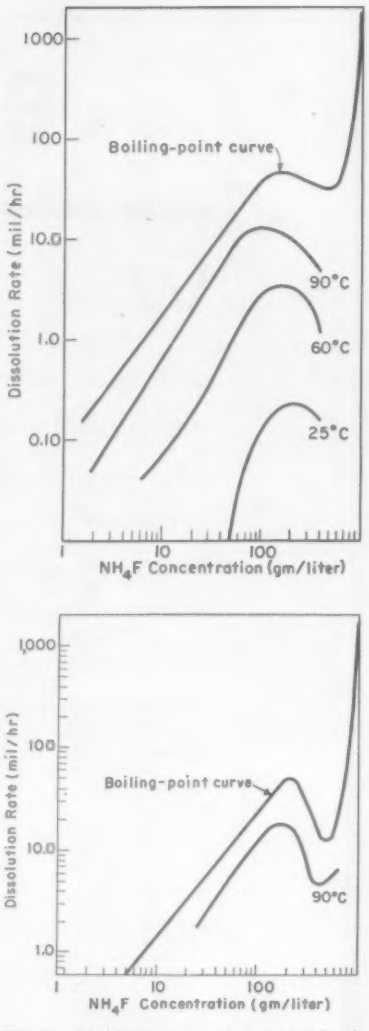

FIG. 2. Dissolution rates of zirconium (top) and Zircaloy-2 (bottom) in ammonium fluoride. Solution rate differs for various metals but increases with temperature and concentration

In one case, the surface of a Zircaloy-2 ingot had been machined and considerable scrap generated. The ingot showed an average Brinell hardness (BHN) of 189. Some of the turnings were degreased and arc-melted to a button having a BHN of 207. Such increases in hardness are typical and indicate the oxygen-nitrogen pick-up in the machining operation. Three separate quantities of the turnings were degreased and etched in a 30% ammonium-fluoride solution at room temperature until a 6% weight loss was obtained. The turnings were removed from the bath, rinsed with 5% hydrochloric acid to dissolve a fine black deposit on the turnings (apparently

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FIG. 3. Strip of 0.065-in.-thick zirconium uniformly reduced to 0.005 in. in NH_4F solution with variation of <0.0005 in. over entire surface. Alloys are as easily dissolved. This suggests precision decladding, leaving uranium core exposed

tin), then washed in water, acetone rinsed and dried. The batches were later arc-melted in argon to massive ingots, which tested at 181, 185 and 185 BHN. Analyses indicated an appreciable drop in oxygen from the raw turnings to the treated ones.

When an ammonium fluoride solution has been used in this application for some time, soluble zirconium is present in considerable quantities. If a hot 20% NH_4F solution has been used, cooling to room temperature suffices to cause a large percentage of the zirconium to crystallize from the solution as $(NH_4)_3ZrF_7$. Had more dilute solutions been used, the addition of ammonium fluoride and cooling produces the same effect. The crystals are coarse and easily removed either by filtering or decanting. They are quite readily dissolved in water. The addition of ammonia causes all of the zirconium to be recoverable as hydrous oxide, while ammonium fluoride is regenerated in the filtrate.

Fuel-Plate Treatment

It was observed in our experiments that the dissolution of these metals in ammonium fluoride was remarkably uniform on every surface. For example, a strip of 0.065-in.-thick zirconium could be uniformly reduced to 0.005 in. with but slight variation, generally <0.0005 in., over the entire surface. (See Fig. 3.)

A logical step was the attempt to declad a Zircaloy-2-cladded fuel plate by this means. It was found possible to remove the cladding with precision from STR-type plates, leaving exposed the uranium-alloy fuel element (Fig. 4).

It was further discovered that the alloys of uranium and zirconium are as easily dissolved as is zirconium. This opens up a new possibility in the reprocessing of spent nuclear fuel elements—the solubilities of the complex fluorides and simple fluorides in ammonium-fluoride solution present a gross method of separating zirconium, uranium and fission products.

The metals Nb, Zr, Hf, U, Th, Cr and Ti form soluble complex fluorides that are also soluble in ammonium-fluoride solutions. In most cases, a large increase in ammonium-fluoride concentration causes the complexes to crystallize. The alkali metals form water-soluble fluorides, but in the presence of Zr or Ti, insoluble complexes of the form Na_2ZrF_6 are formed. The Group II metals Ca, Sr and Ba form insoluble fluorides in ammonium-fluoride solution and so do the rare-earth metals.

An irradiated fuel element of the STR type, containing fission products, could be decladded and later completely disintegrated in ammonium-

FIG. 4. Decladding of STR-type fuel plates. Left to right, plate stripped in 1 min, original plate, plate stripped in 30 min

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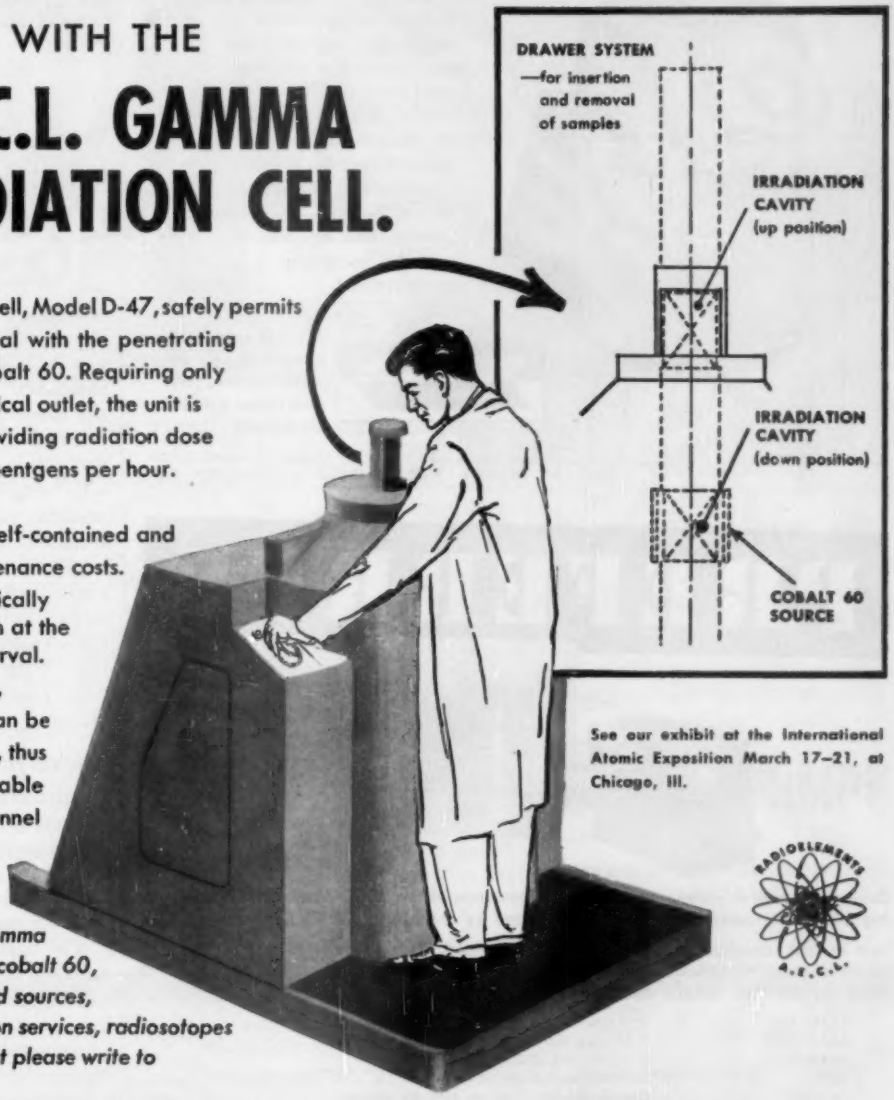

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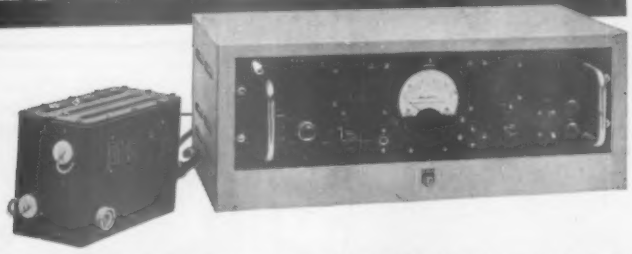

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This article starts on page 94

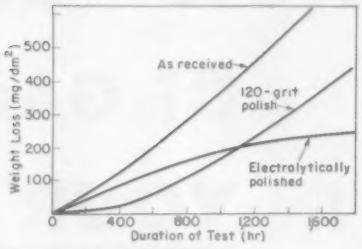

FIG. 5. Effect of surface condition on corrosion of zirconium in boiling 20% hydrochloric acid

fluoride solution. The conditions of dissolution are such that iron containers or tanks lined with rubber or plastic may be used. The solution will contain zirconium and uranium, while the insolubles will consist chiefly of the nonvolatile fission products. A filtration step would isolate the bulk of the fission products. When the clear solution is cooled, the uranium separates completely, together with the bulk of the zirconium, as mixed crystals.

These crystals consist of $(NH_4)_3ZrF_7$ and a deep-green crystal thought to be a U^{+4} fluoride. It was found that the uranium salt crystallized only when considerable zirconium was also present in solution. The mixed crystals when leached with a minimum of cold water yielded the zirconium to solution, but the uranium complex remained insoluble. While this system has not been fully explored, the implications are obvious.

Electrolytic Polishing

Attempts to influence the actions of ammonium fluoride on zirconium and hafnium by making the zirconium anodic and cathodic in an ammonium-fluoride electrolyte produced unexpected results.

The application of voltages as high as six volts did not produce cathodic protection, the metal continued to dissolve, and gases were evolved from the entire surface. However when the zirconium (or hafnium) was made anodic, the surface of the zirconium acquired a brilliant polish, which we describe as an electropolished surface. When a piece of zirconium tube was used as the anode, the inside surface also acquired this very fine finish. The stoppage of the current resulted in a rapid deterioration of this surface so the pieces had to be removed from the bath while the

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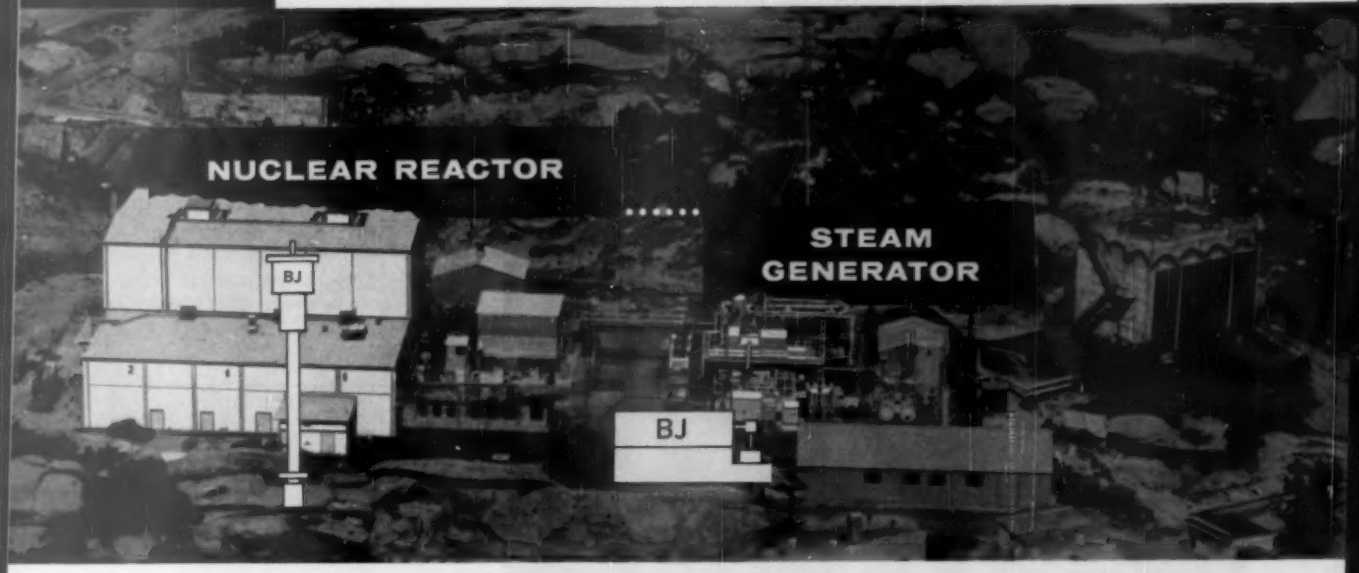

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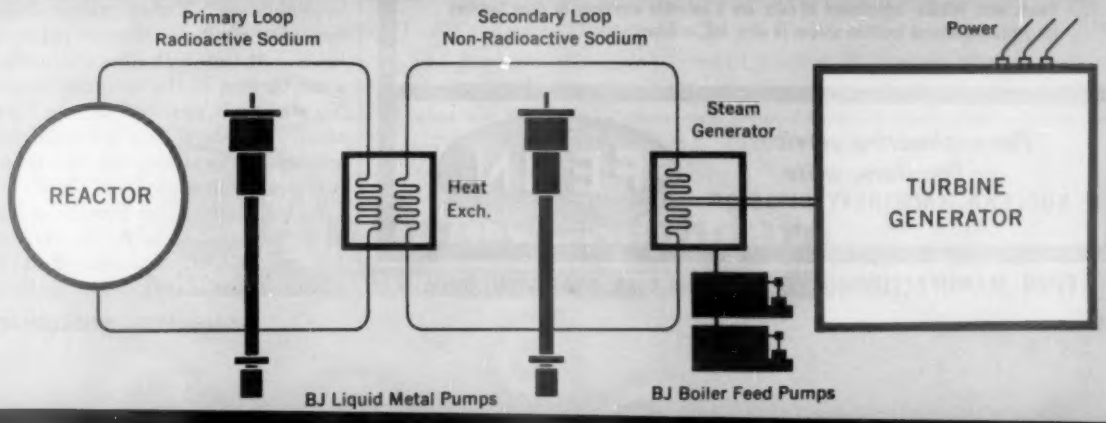

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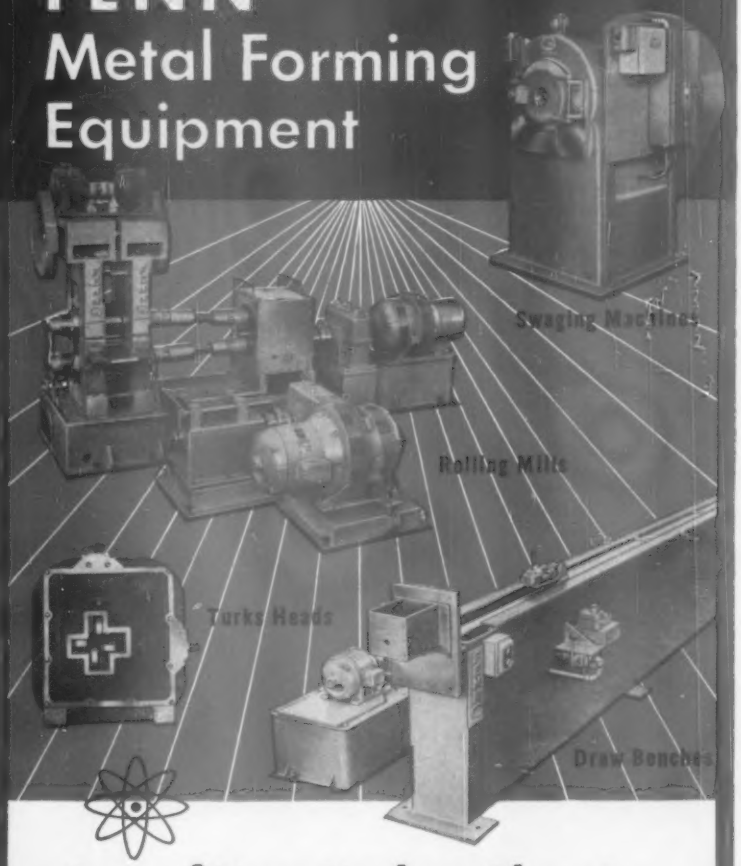

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current was still passing and washed immediately in cold water.

These finishes are believed to be relatively permanent because they have shown no deterioration or dulling over a period of 18 months. They have been produced equally well on zirconium, hafnium and the Zircaloys. Further tests have shown that this finish enhances the corrosion resistance both in strong acids and also in wet carbon dioxide at elevated temperatures. Some results of these experiments are shown in Figs. 5 and 6.

The best conditions for electropolishing appear to be a solution of about 500

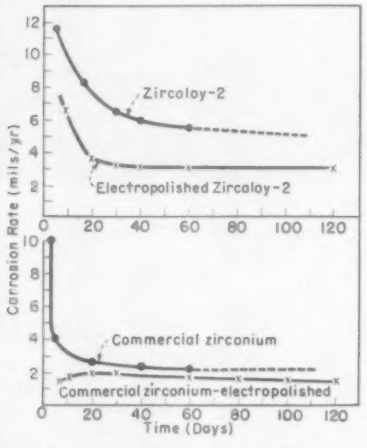
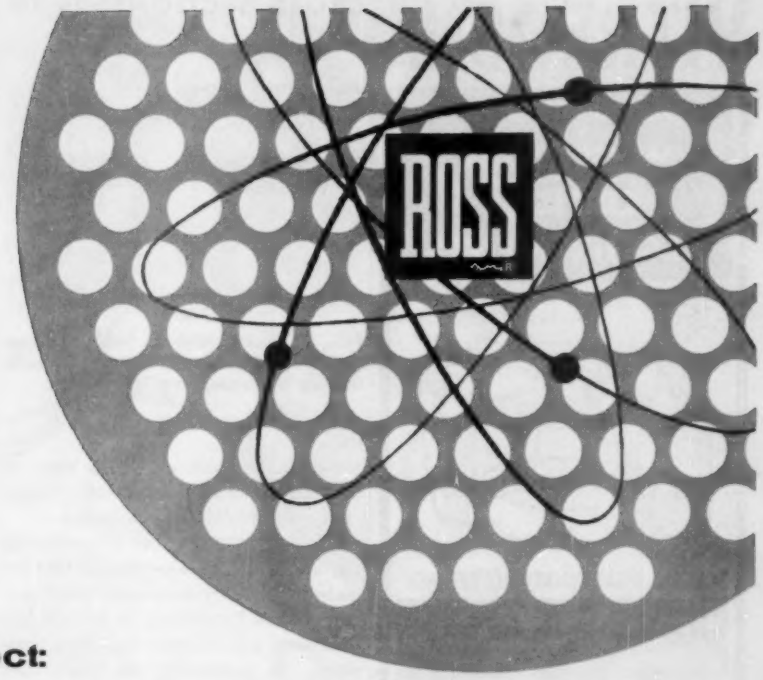


FIG. 6. Corrosion tests of zirconium and Zircaloy-2 in wet CO_2 at 500° C. Electropolishing provides relatively permanent protection

gm per liter of ammonium fluoride at a *p*H of 6.5–7. The cathode is graphite, the anode the piece to be polished. Because these metals are easily attacked by ammonium-fluoride solution, the specimen is placed in the plating bath with the voltage applied, such that a current density of 1–4 amp/dm² is established. Higher current densities will result in shorter polishing times. At very high current densities, some burning of the specimen occurs. No stirring is provided for the operation. In general, only a few minutes are required to achieve the best finish. A typical result is shown in Fig. 7.

In several runs, the average loss of metal appeared to be in the order of 1–3 mg/dm²/hr. Another effect of this treatment is that minute faults in



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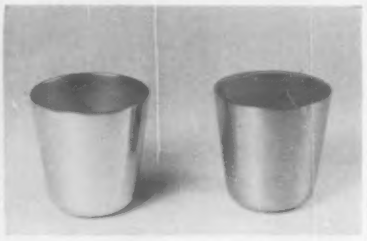

FIG. 7. Electropolished (left) and unpolished zirconium crucibles. Optimum finishing is obtained in a few minutes

the metal surfaces are clearly seen, so that defects in fabrication can be more easily discovered and eliminated.

Recently the method of preparing zirconium and Zircaloy sample tabs for high-temperature-water and steam corrosion tests by etching in a nitric-hydrofluoric acid mixture has been criticized. It is thought at times that zirconium compounds containing oxygen and fluoride are left in the surfaces of the samples. Such variation of surface reduces the validity of the tests. An electropolished finish by the technique described herein is suggested as a possible solution to this problem. The method is easily controlled and duplicated; the surfaces produced are uniform; and frequently minute physical defects in the surface are clearly revealed. The validity of the tests can be further increased by discarding such defective samples.

Conclusions

Although we have not studied the economics of ammonium fluoride usage deeply, this should not constitute a problem. In the scrap recovery, the fluoride is recirculated. We feel that the process would be economical even if the ammonium fluozirconate were discarded.

So far as the fuel-element reprocessing is concerned, all the ammonium fluoride that combines with the zirconium or niobium would be recovered, while that which goes with the uranium would be lost. However, considering the value of the uranium, this loss is small. It is also conceivable that all of the fluorine tied up in fission-product fluorides can be returned to the system.

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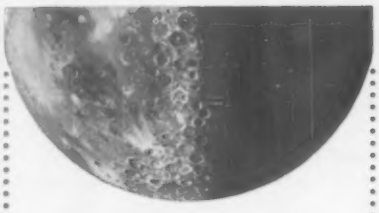

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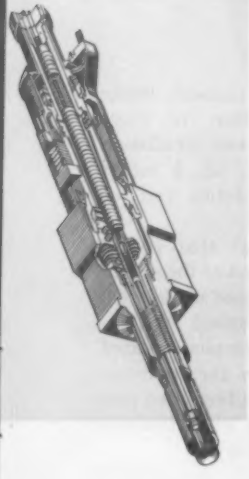

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Neutron, Gamma Measurements for In-Pile Power Monitoring

By A. C. LAPSLEY
Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, South Carolina

Safety and performance of a nuclear reactor can be improved when information is available on the distribution of power within the pile. The necessary information, however, can only be obtained with certainty with monitors located inside the reactor, and such in-pile monitoring is a difficult problem, for the monitor components must withstand intense radiation.

We have developed neutron- and gamma-sensitive monitors for use inside reactors. The neutron monitor uses a thermocouple to measure temperature differentials generated in a uranium-aluminum button, and the gamma monitor uses an ionization chamber. Both monitors are insensitive to radiation damage and have a long life in piles that operate at a high power density. Several monitors located in a pile can be used to indicate the power distribution.

What to Measure

The first factor to consider is which pile characteristic is to be measured. Power-density measurements cannot be made directly, but the density is related to both neutron and gamma flux, and devices that measure either of these variables furnish the needed information.

One method for internal monitoring has been pursued at Brookhaven (*1*), the Materials Testing Reactor (*2*) and Battelle Memorial Institute (*3*): Monitors determine the distribution of neutron flux with a wire placed in the pile. After the wire is irradiated, it is withdrawn, and the induced activity is measured along its length. The distribution of neutron flux is the same as the distribution of activity along the wire.

For some applications, this method has limitations: (a) The information is not supplied continuously. (b) Information is furnished on the integrated flux over the period of exposure rather than on instantaneous flux. (c) There is a time delay between irradiation and data availability. (d) A rather involved mechanical setup can be required.

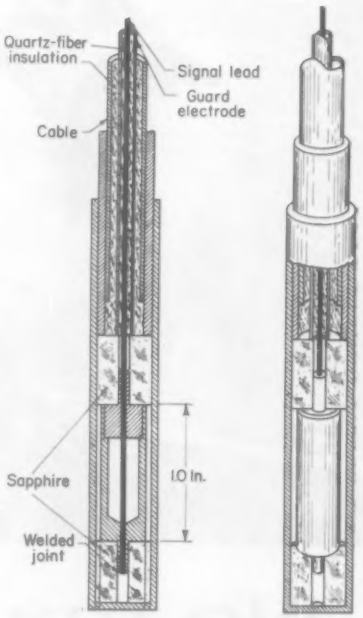

FIG. 1. Gamma monitor for in-pile measurement is tiny ionization chamber with insulators designed to withstand irradiation

Another monitor (*4*) that should overcome all but the first of these limitations has been developed at Battelle. It uses a thermopile coated with enriched UO_2. The thermopile is heated by fissions induced in the uranium. This basic principle has been used previously (*5–7*) but not with monitors that can operate inside a pile.

Gamma Monitor

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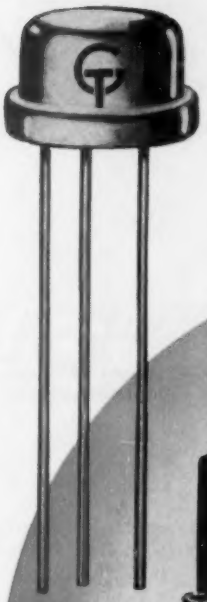

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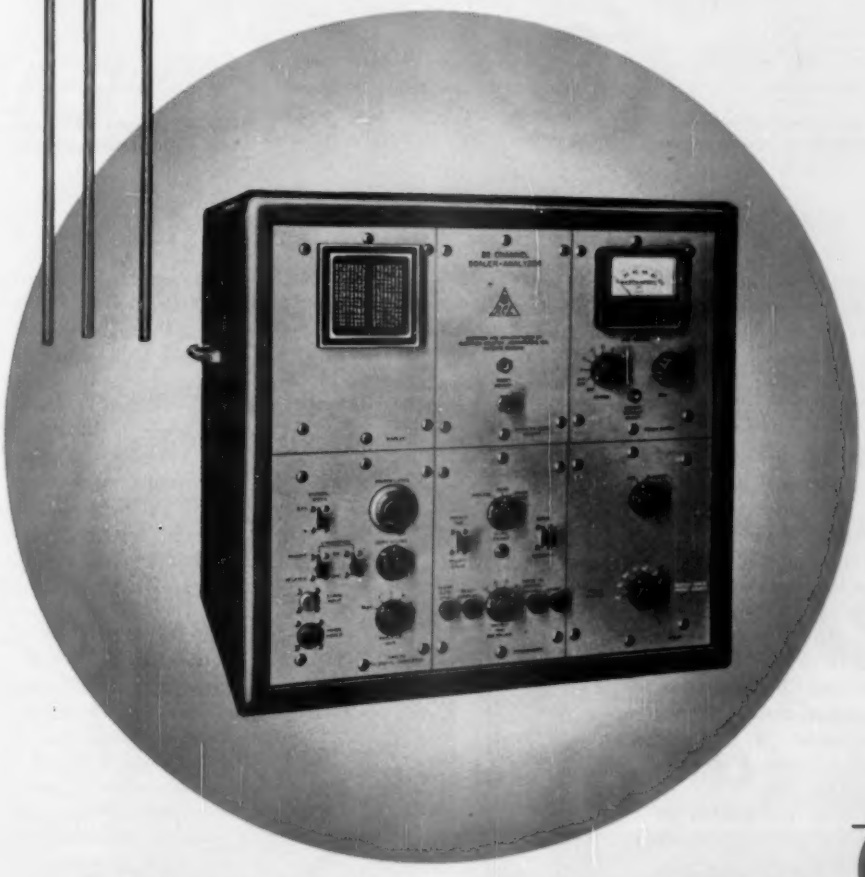

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ion chamber—is shown in Fig. 1. The most critical component is the insulation, for it is the most likely to be damaged by reactor radiation. Synthetic sapphire was selected as the most promising material and has held up well under irradiation.

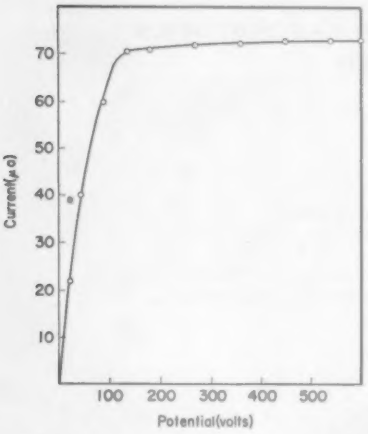


FIG. 2. At 10^9 r/hr, current-voltage curve of gamma monitor shows saturation above 150 volts

The chamber itself is cylindrical and made from Type-1100 aluminum. The gap between the electrodes is 0.038 in., and the volume is 0.0436 in^3 (0.713 cm^3). Sensitivity at NTP is 7×10^{-14} amp/r/hr.

A special electrical cable carries the signal from the chamber. The guard electrode electrically shields the signal lead from the voltage supplied to the chamber on the cable's outside sheath. It is operated at the same voltage as the signal lead so that the signal lead collects no ion current from the cable.

The metal parts of the cable are Type-1100 aluminum. The insulation, just as in the chamber, must be special to withstand radiation. A synthetic quartz fiber with a boron content of <100 ppm is used.

Chamber and cable are welded together, but there is no gas seal between the two. There is a gas seal on the end of the cable farthest from the chamber so that the sensitivity of the chamber is a function of the temperature ratio between chamber and cable. There is no indication that this mode of operation appreciably affects performance.

An in-pile test was made to a total exposure of 3×10^{12} r, and the performance was satisfactory throughout the test. A voltage-saturation curve at a flux level of 10^9 r/hr is shown in Fig. 2. There was no change in voltage-current characteristics during the test.

The cable also performed quite satisfactorily. Resistance between guard electrode and jacket was about 10^8 ohm/ft at a 10^9-r/hr gamma flux, and there was no appreciable increase during the 3×10^{12}-r exposure.

Neutron Monitor

Our neutron monitor uses a thermocouple to measure the heat generated by *n,f* reactions in uranium and is known as a "neutron thermometer." It is constructed as shown in Fig. 3. An alloy button formed from uranium and aluminum is welded to the aluminum jacket of the thermocouple. The entire assembly is contained in an air-filled housing.

The thermocouple requires special radiation-proof electrical insulation; magnesium-oxide was used. The thermocouple wires are iron and constantan.

The neutron thermometer responds to neutron flux through heating induced by fissions in the alloy button. This heat is removed from the button by conduction, both along the thermocouple jacket and through the air, and by convection and radiation. The neutron flux therefore induces a temperature differential between button and housing that is a function of flux level. The temperature differential is measured with the thermocouple shown in Fig. 3 and a second one that measures the temperature of the housing.

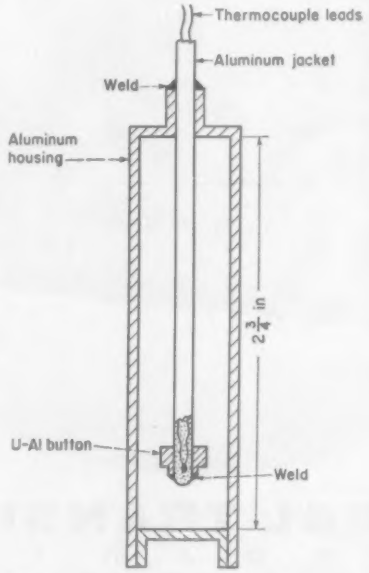


FIG. 3. Neutron monitor has thermocouple inside uranium-aluminum button. Second thermocouple (not shown) monitors jacket temperature

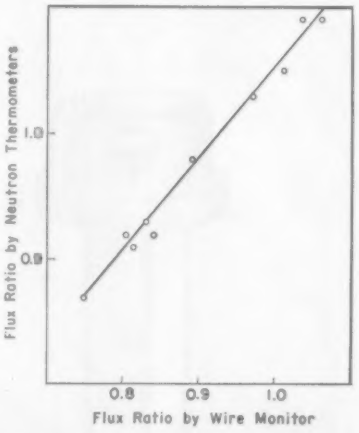
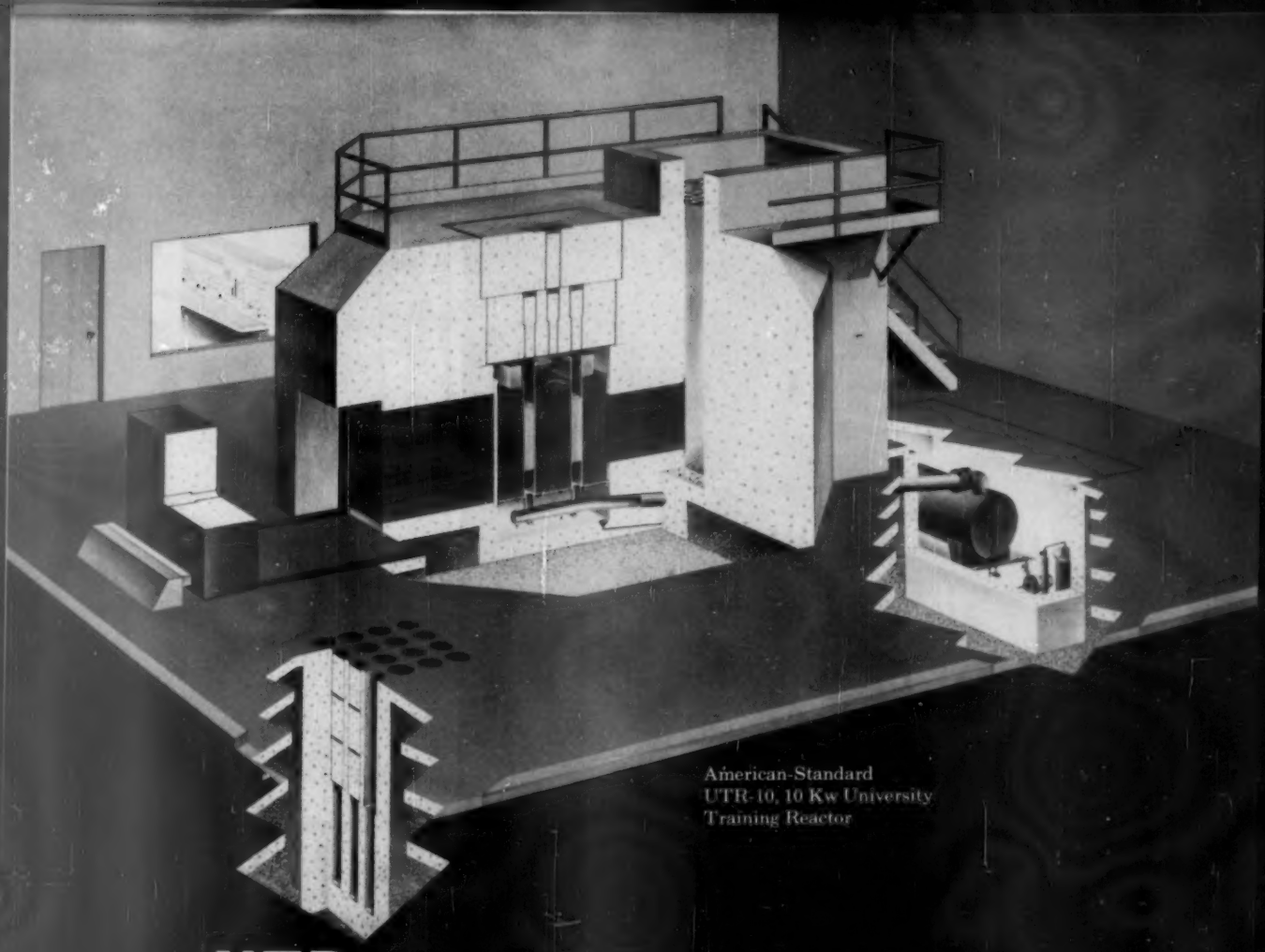


FIG. 4. Neutron-monitor readings agree with measurements by wire activation

The system was tested by inserting two of the units into different locations of a pile and comparing their outputs with the neutron flux determined by the activation of wires. The relative flux levels between the two locations was varied by moving control rods. The results are shown in Fig. 4.

The two neutron thermometers have also been tested by measuring temperature differentials at different power levels. The results are plotted in Fig. 5. The response is nonlinear, as is to be expected if excessive heat generated in the button is lost by convection and radiation. The linearity can be improved by decreasing the length of thermocouple inside the housing as this will increase the heat lost by conduction.

The neutron thermometers have been exposed to a total neutron exposure of 10^{21} n/cm^2 and a gamma exposure of 5×10^{11} r. There is no indication that the irradiation affected their performance. The life of the thermometers may be considerably greater than 10^{21} n/cm^2 and will be ultimately limited by burnup of the uranium. Buildup of Pu^{239} replaces the U^{235}, and the life is controlled by



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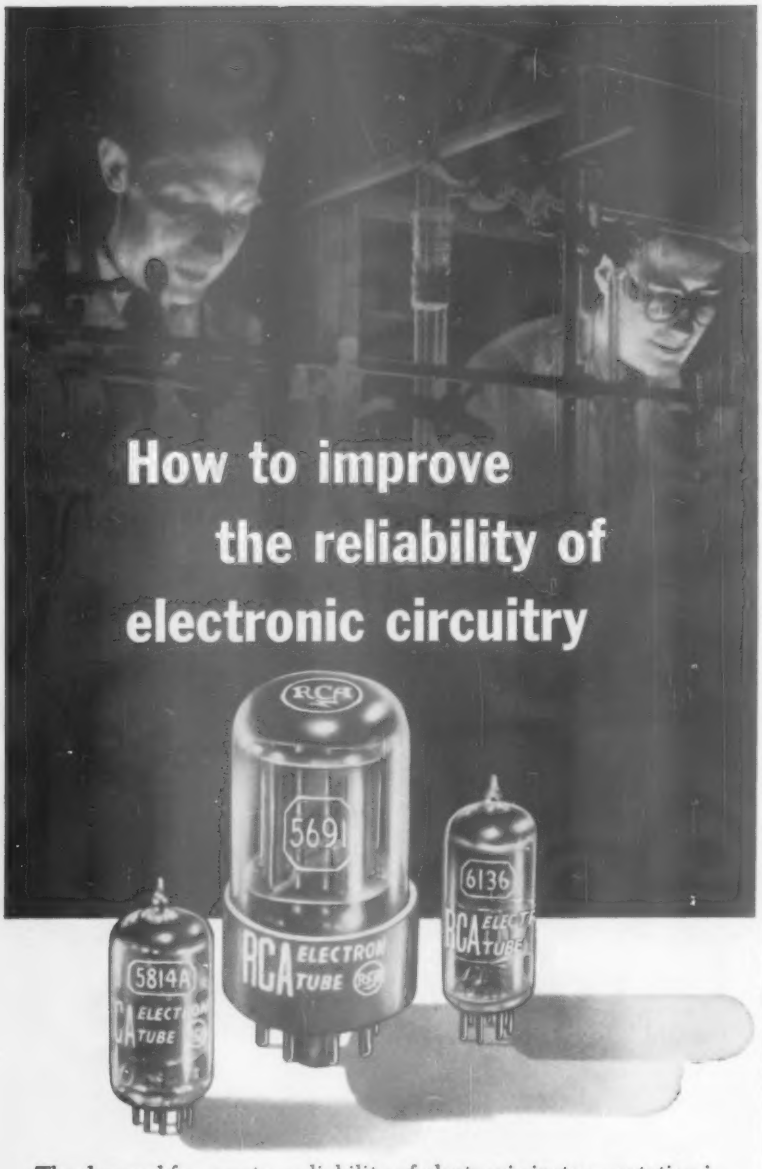

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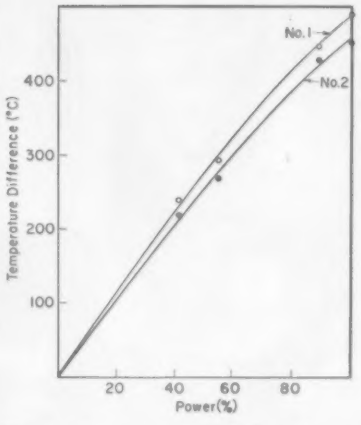

FIG. 5. Response of neutron monitor is slightly nonlinear with power

the depletion of U^{238}. Calculations show that an exposure of 5×10^{22} n/cm² would reduce the sensitivity by about 10%.

The dynamic range of the neutron thermometers is about one decade with a time constant of ~0.5 min. The range is limited by heating due to delayed gamma activity in a pile following its shutdown and beta activity of fission products in the button. Delayed gamma activity produces about 1% of the total heating at full power, and the beta activity contributes another 3%.

* * *

The author expresses his appreciation to V. F. Hanson and R. L. McCarthy of the Engineering Research Laboratory, E. I. du Pont de Nemours & Co., Wilmington, Delaware, who designed the special cable used with the gamma chamber. The author also received considerable help from S. Mirshak of the Savannah River Laboratory, E. I. du Pont de Nemours & Co., Aiken, South Carolina, who did the initial design work on the neutron thermometer.

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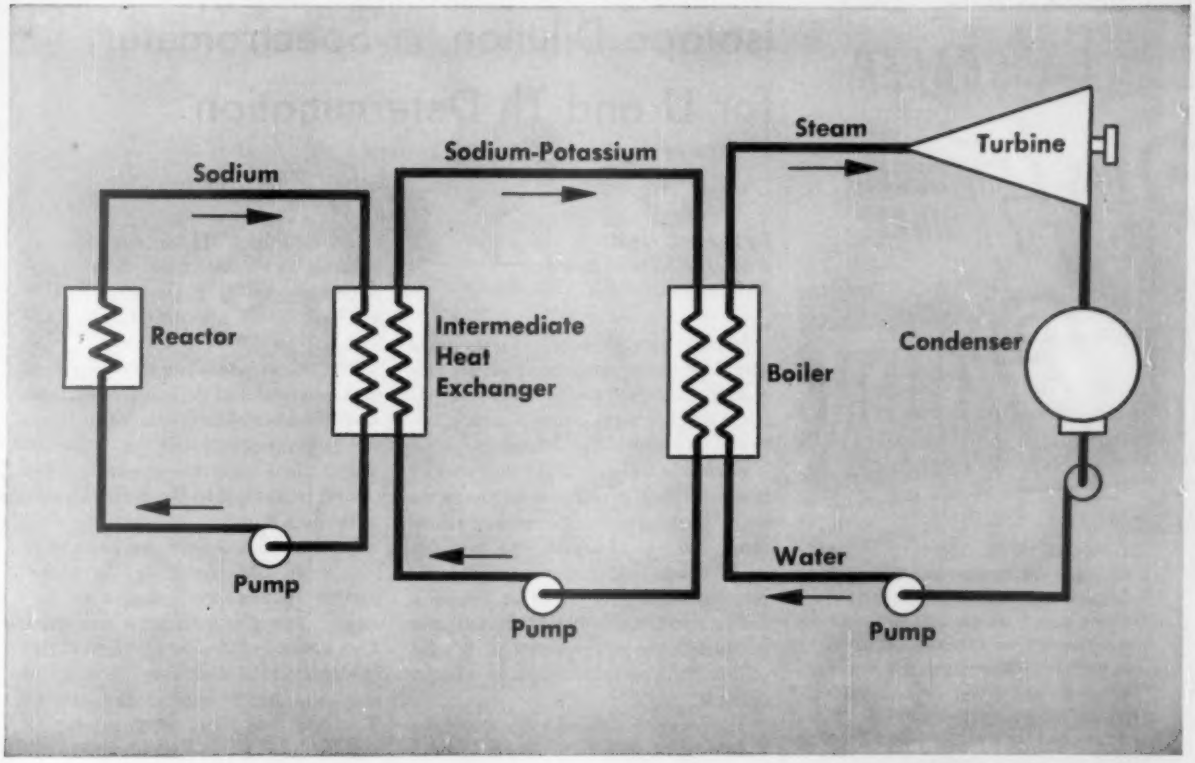

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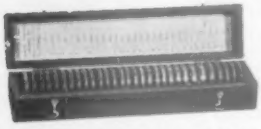

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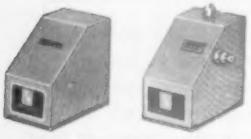

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Isotope Dilution, α-Spectrometer for U and Th Determination

By L. E. HOWARD*
Bureau of Mineral Resources
Melbourne, Australia

In assaying rock samples for uranium and thorium, physical methods are frequently preferred to chemical analysis because they are quicker and more suited to a routine procedure.

Except in the case of the fluorimetric method (*1*), the physical methods require the measurement of nuclear radiations from the sample. If uranium and thorium both occur in a rock sample, particularly if either or both are not in equilibrium with their daughter products, the interpretation of the radiometric measurements is usually difficult.

For assaying rock samples, a method should be applicable to concentrations of 0.05–5% uranium or thorium. Rocks containing $<0.05\%$ uranium or thorium are of no commercial significance, and rocks containing $>5\%$ are uncommon and can be assayed by diluting in a known ratio.

Separate gamma and beta counts (*2*) enable the state of equilibrium of a uranium sample to be determined and allowed for. It also enables assays to be made if there is thorium present, provided the uranium can be assumed to be in equilibrium with its daughters.

Another method (*3*) makes use of the difference in the gamma-ray spectra of uranium and thorium minerals. Scintillation-counter measurements are made of the gamma activity in two energy channels in which the relative intensities of the radiations from the uranium and thorium series are as dissimilar as possible. If a beta count is also made, the concentrations of uranium and thorium may be determined even if the uranium is not in equilibrium due to escape of radon. Emanation methods (*4*) involve the measurement by alpha counting of the concentrations of the inert gases radon and thoron (Em^{220}), which are removed from the rock sample by melting or boiling a solution. Radon can be distinguished from thoron by its much longer half-life. These methods are accurate and sensitive but the assumption is necessarily made that the U^{238} and Th^{232} are in equilibrium with Ra^{226} and Ra^{224}.

The fluorimetric method involves both physical and chemical procedures and depends on the atomic rather than the nuclear properties of uranium. The method is extremely sensitive but cannot be applied to the determination of thorium.

Ionization chambers can be used in two ways. In the first, the alpha-particle pulses are counted or the steady ionization current is measured. This method obviously offers no means of determining the U-to-Th ratio or the equilibrium state of the sample. The ratio has been estimated (*5*) by adding an absorber and observing the change in counting rate. The accuracy would be rather low and, moreover, no determination of the equilibrium was made. The second way of using an ionization chamber is to measure the alpha-particle energies by observing the pulse amplitudes. In this way the alpha spectrum can be drawn and the states of equilibrium of both series can be determined. However, for good energy resolution it is necessary to deposit the sample in the form of a very thin film on a metal plate. However, the small sample will yield a low counting rate. This difficulty has been partly overcome (*6*) by using a gridded ion chamber with large-area electrodes.

The isotope-dilution method using a mass spectrometer has been used (*7*) to determine uranium and thorium in granite. The method is extremely sensitive, but the solid-source mass spectrometer and the complex chemical procedures make it unsuited to general use.

The method we propose here in effect combines the last two methods. That is, it uses a gridded ion chamber as a simpler alpha spectrometer and an isotope-dilution technique to determine concentrations. The chemical procedures are also simplified because isotopic weights are not measured but only the ratio of their weights. The sensitivity is much greater than the

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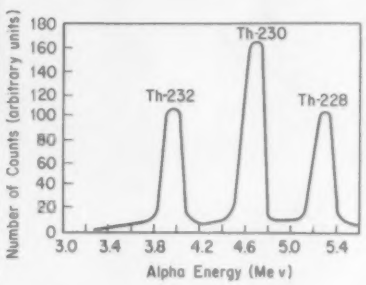

TYPICAL THORIUM alpha spectrum

simple method of using a gridded ion chamber because the material is deposited on the negative electrode as a practically pure thorium salt rather than as a powdered rock sample of relatively low thorium or uranium content.

Isotope Dilution

The simplest case for applying isotope dilution is that in which the normal form of the element consists of a single isotope but where the element can also be obtained as a different isotope not mixed with the normal one. The procedure is to take an accurately weighed quantity (W gm) and bring it into solution (or at least ensure that all the element to be estimated is brought into solution). A known amount (W_2) of the different isotope, which is usually referred to as the spike, is added and the two are thoroughly mixed.

Some of the element is extracted chemically from the sample and the relative isotopic abundance of the extracted element is measured. Let R be the ratio of the weight of the normal isotope to the total weight of the element in the extracted sample after mixing with the spike, i.e.,

$$R = W_1/(W_1 + W_2)$$

where W_1 = weight of element in the sample to be assayed. Then

$$W_1 = [R/(1 - R)]W_2$$

and the percentage concentration of the element in the original sample is immediately determined in terms of the known quantities R, W and W_2 as

$$\left(\frac{W_1}{W} \cdot 100\right)\% = \left(\frac{R}{1-R} \cdot \frac{W_2}{W} \cdot 100\right)\%$$

Two elements in sample. The principle can be extended to the case where both elements are present in the sample and the spike in ratios that are known or can be determined.

Let W_a be the weight of the element in the sample and W_{a1} and W_{a2} the weights of the isotopes in the sample, with $R_a = W_{a1}/W_a$. Similarly let W_b, W_{b1} and W_{b2} be the weights of the spike and of the same two isotopes in the spike and $R_b = W_{b1}/W_b$. Then in the mixture

$$R = \frac{W_{a1} + W_{b1}}{W_a + W_b} = \frac{R_a W_a + R_b W_b}{W_a + W_b}$$

W_a is the only unknown quantity in this equation, which can be re-arranged as $W_a = W_b(R_b - R)/(R - R_a)$. The percentage concentration in the sample is therefore

$$\left(\frac{W_a}{W} \cdot 100\right)\% = \left(\frac{R_b - R}{R - R_a} \cdot \frac{W_b}{W} \cdot 100\right)\%$$

Since the uranium and thorium isotopes emit different characteristic alpha particles, the relative abundances can be determined from the alpha-activity ratio and the known half-lives. We may therefore replace the mass spectrometer by the simpler and less expensive alpha spectrometer. A gridded ion chamber used as an alpha spectrometer has adequate resolution to separate clearly the thorium isotopes, which emit alpha particles with energies of 3.98 Mev (Th^{232}), 4.68 Mev (Th^{230}) and 5.3 Mev (Th^{228}).

Experimental Procedure

In many instances it will be evident from other considerations that only thorium or uranium is present in the sample and not a mixture.

Determination of U (Th absent). A normal thorium compound ThO_2 should be added as a spike. The thorium used should be checked with the spectrometer to ensure that it does not contain ionium (Th^{230}) to a measurable degree. If ionium is present (it was not present in the thorium salts used by us), a correction can be made.

The rock sample and a weighed amount of ThO_2 are dissolved in acid solution. Boiling in nitric or sulfuric acid for a few hours is usually sufficient to bring the thorium into solution but some refractory thorium ores require more drastic treatment (*8*).

The thorium extraction is less critical since all the thorium need not be extracted. The only impurities that

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This article starts on page 112

would cause trouble are uranium and polonium since they emit alpha particles with energies in the range investigated. Thorium has been separated by successive precipitations as iodate and oxalate, followed by ignition to the oxide and conversion to the nitrate.

The extracted thorium nitrate must be deposited as a very thin film on an aluminium disk. We use a modification of the Zapon-lacquer technique. About 30 mg of thorium nitrate is dissolved in 20 ml of ethyl alcohol. About 50 ml of clear metal lacquer thinner is added and thoroughly mixed. Finally, 5 ml of clear metal lacquer is added and the mixture is shaken.

A layer of the lacquer is applied with a fine brush to the disk, dried for a few minutes under a heat lamp and then ignited over a Bunsen burner. The resulting layer is almost invisible. A single layer was found adequate as it produced as many pulses per second as the analyzer could measure.

An alpha spectrum is now obtained on the spectrometer for the extracted thorium (see figure). The Th^{230}/Th^{232} ratio in the mixture is calculated from the spectrum. If it is assumed that the ionium is in equilibrium with U^{238}, the amount of uranium can be calculated. If R is the measured Th^{230}/Th^{232} ratio, then

$$R = (W_1/A_1T_1) \cdot (A_2T_2/W_2)$$

where W_1, A_1, T_1 are the weight in the mixture, atomic weight and half-life of ionium, and W_2, A_2, T_2 are similar values for Th^{232}. Therefore

$$W_1 = RA_1T_1 \cdot W_2/A_2T_2$$

If W_3, A_3 and T_3 are similar values for U^{238}, then

$$W_3 = RA_3T_3 \cdot W_2/A_2T_2$$

and the uranium concentration in the mixture is $R(W_2/W)(A_3T_3/A_2T_2)100$ %. For greatest accuracy, the peak heights in the alpha spectrum should be as nearly equal as possible. It is usually possible to obtain a rough estimate of the activity of the sample by a simple beta or gamma count. To obtain equality of peak heights, about three times as much thorium should be added as the estimated amount of uranium in the sample.

Determination of Th (U absent). The procedure in this case is precisely

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the converse of the previous. A known amount of uranium in the form of pitchblende is added. The pitchblende is checked to ensure that the ionium is in equilibrium with the U^{238} but it is extremely unlikely that this would not be so. Also, there should be no thorium from the Th^{232} series in the pitchblende. The chemical procedures are the same as in the previous example and the same equations apply. However, W_2 is now an unknown quantity and W_3 (the amount of uranium added) is known.
Therefore

$$W_2 = \frac{1}{R} \cdot \frac{W_3}{A_3 T_3} \cdot A_2 T_2$$

$$\text{Th}\,\% \doteq \frac{1}{R} \cdot \frac{W_3}{W} \cdot \frac{A_2 T_2}{A_3 T_3} \cdot 100\,\%$$

In radiometric assaying it is usual to express results as percentage U_3O_8 or ThO_2 equivalent. To do this, the calculated percentages must be multiplied by 1.179 and 1.125, respectively.

Simultaneous determination of U and Th. Some thorium minerals, e.g., monazite and thorite, frequently contain significant amounts of uranium. In this case the procedure is more complicated. Two methods are possible.

1. A spectrum is taken of thorium extracted from the sample without adding any spike. This enables the Th/U ratio in the sample to be obtained. A suitable spike is added to the original sample and some thorium extracted. From the new spectrum, the total thorium content (i.e., thorium +ionium) of the original sample is calculated, and from the previously determined ratio the individual concentrations of thorium and ionium may be calculated.

2. An alternative method that requires only one thorium extraction involves measuring the 5.3-Mev Th line in addition to the other two. It also requires as a spike some thorium that is isotopically different from normal thorium and from ionium. If normal thorium is separated chemically from its daughter products, the relative amounts of Th^{232} and Th^{228} are the same as in the series in equilibrium. However, the Th^{228}/Th^{232} ratio reaches a minimum of about one-half the equilibrium ratio after six years and then increases again to its equilibrium value. Therefore a thorium salt that was separated about six

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years earlier can be used as a spike to determine the amount of normal thorium in a sample. The amount of uranium present can then be separately determined from the ratio of the ionium peak height to that of Th^{232} or Th^{228}.

The calculations in these two cases are similar to those in the preceding two cases, though longer.

Apparatus

The apparatus includes an ion chamber, high-voltage supply, preamplifier, amplifier, cut-off amplifier and multichannel analyzer. The circuits are reasonably standard.

The pulses from the ionization chamber are ~100 microvolts/Mev of alpha-particle energy when measured on the grid of the first amplifier tube and are proportional to the alpha energy. These pulses are amplified to 25 volts for 3-Mev alphas. They are then passed through a subtracting circuit so that the pulse amplitude is decreased by 25 volts. The resulting pulses are amplified further by a factor of four and fed into a multichannel analyzer. This analyzes the pulses into 24 channels from which the spectrum can be plotted.

In practice, the subtractor bias and the gain of the following amplifier were arranged so that the analyzer recorded the spectrum between 3.7 and 5.6 Mev. All pulses corresponding to higher-energy alpha particles were recorded together in the final channel.

Ion chamber. The ion chamber was of the gridded-parallel-plate type. The electrode structure was supported on polystyrene insulators inside a 10-in.-dia steel cylinder. As the electrodes were at least 2 in. from the walls of the cylinder, the background count was negligible. The negative electrode and the collecting electrode were 10-cm-dia circular disks, 8 cm apart. The grid consisted of 38-SWG copper wires 0.15 cm apart and 2 cm below the collecting electrode.

It can be shown that if the shielding efficiency of a grid (e) is defined as 1 − (charge induced on collector)/(charge present near negative electrode), then e is given by $e = 1 - k(1 - C'/C)$, where C' is the capacity between the grid wires and the two electrodes and C is the capacity between a hypothetical plane sheet in the plane of the grid wires and the two electrodes. The capacity C' is given by

$$C' = \frac{1}{2d \log\left[\frac{2a}{c}\frac{1}{\theta_1'(0)} \cdot \theta_1\left(\frac{b}{a}\right)\right]}$$

where a is the distance between the two plane electrodes, b is the distance from the grid to the negative electrode, c is the radius of the grid wires, and d is the distance between the centers of adjacent grid wires. The theta-function (ϑ) parameter is $\tau = d/2a$.

On substituting the above values, the shielding efficiency of the grid is ~99%. Lack of resolution due to induction on the collecting electrode by negative ions may be safely ignored.

The chamber was evacuated with a mechanical pump and then filled with commercial argon (99.8% pure) to a pressure of 2.5 atmospheres. No additional purification was necessary. A negative voltage of 2 kv was applied to the negative electrode and the collecting electrode was earthed through a 100-megohm load resistor. There was a slight (<2%) change of amplitude of the pulses with a change of EHT voltage between 500 volts and 2,000 volts, indicating the negligible effect of electron-capturing impurities such as oxygen in the gas.

The preamplifier consisted of a 6AK5, specially selected for low-grid current and noise. It operated as a triode amplifier with a gain of two. The main amplifier consisted of three feedback rings of three, each stabilized by negative feedback from the cathode of the final tube to the cathode of the first tube. It had a differentiating time constant of 8 μsec and an integrating time constant of 10 μsec.

The multichannal analyzer was similar to that described by Wilkinson (*10*) but with slight modifications and fewer channels. The channel counts are recorded on standard telephone registers. The analyzer can therefore count only at a slow rate, and a blocking pulse applied to the input limits the rate at which pulses are fed into the analyzer to about 6/sec. This slow counting rate is no great disadvantage since the alpha-emission rate of the thin thorium film is only of this order. A useful spectrum can be obtained in about 15 min. It should be noted that the results would not be as accurate with a single-channel analyzer. This is because every alpha particle in the selected band is recorded by the alpha spectrometer and the number of pulses in a certain peak is clearly determined,

whereas if a single-channel analyzer is used, the number of pulses in a peak must be determined by drawing a curve through a finite number of points.

Sensitivity, Accuracy

There is no lower limit to the concentrations in rocks that can be measured by this method. However, the lower the concentration, the more difficult are the chemical extractions because the amount of rock required and the possibility of contamination are both greater.

Rocks have been assayed by this method with activities as low as 0.1% U_3O_8 or ThO_2 equivalent. This lower limit could probably be extended to 0.01% without unduly complicating the chemistry.

The accuracy is determined mainly by the statistical fluctuations in the number of alpha counts in the individual lines. It is therefore approximately proportional to the square root of the counting time. It should be remembered that the isotopic ratio is determined as the quotient of two normal variates. Its variance is therefore approximately proportional to the sum of the variances of the individual counts. This theoretically justifies keeping the heights of the alpha-energy lines as nearly equal as possible.

* * *

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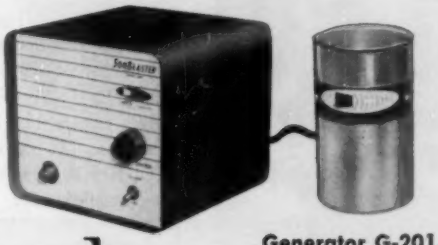

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NUCLEAR ENGINEERING NOTES

EBR-I Starts Up With Mark III Core

After nearly two years since the meltdown of its Mark II core, Experimental Breeder Reactor-I (ERB-I) is back in operation at the National Reactor Testing Station, Idaho Falls, Idaho (NU, Jan. '58, 26). The reactor had been put out of action by a power excursion (NU, Jan. '57, 84) during investigations of the reactor's positive temperature coefficient. Since then it has been generally agreed (NU, Apr. '57, 62) that the positive temperature coefficient was most probably caused by bowing of the fuel elements in the Mark II core due to thermal expansion. It has also been felt that the previously noted resonance instability of EBR I is related to the positive coefficient and thus also depends on this design peculiarity.

On November 11, 1957, EBR-I was started up again with a core, the Mark III, designed expressly to test these hypotheses. Among other things the Mark III can be operated either with or without fuel element bowing. After the new core has been gotten up to full power, Argonne National Laboratory personnel will then be in a position to make positive checks on the effect of this kind of fuel element distortion.

The Mark III design covers two of the main parts of the EBR-I structure: the core and inner blanket. These sections are contained in a double wall tank called the inner tank assembly. Mark III is 9 ft, 5 in. long. The outer wall is constructed of laminated steel discs. The assembly is cooled in the reactor by sodium-potassium alloy.

The third major portion of EBR-I, an outer air-cooled breeding blanket of natural uranium, remains unchanged.

To achieve a more rigid core, a new type of fuel rod was developed for Mark III. Each rod has a zirconium cladding, or protective jacket, three zirconium spacer wires, or ribs, that steady it in relation to others in a fuel assembly, and a triangular tip at the bottom for angular positioning in the core.

Fuel rod assemblies are used in Mark III, rather than the individual rod scheme employed in the original EBR-I design. The rods are contained in hexagonal tubes and are tightened in their container by means of a center tightening rod made of aluminum bronze encased in a stainless steel tube.

This rod has keys along its length that enable it to expand and force the fuel rods out against the side of the hexagonal tube, thus making a rigid assembly that will be free of the bowing effect believed to have existed in the fuel rods in the previous Mark II core.

Fuel assemblies are then inserted in the core and tightened with tapered clamps at the center line of the fuel core, insuring rigidity of the hexagon pack under full power operation.

Each fuel assembly in Mark III contains up to 36 natural and enriched uranium rods, clad with a zirconium alloy, and one tightening rod. Maximum capacity of the core is 252 fuel rods containing 60 kg of enriched uranium.

Provision is made for permitting either series or parallel coolant flow through the inner blanket and core of Mark III, giving greater flexibility to operational testing.

Mark III also includes an extensive temperature measuring system. Thermocouples are located at points in the structure where possible thermal expansion might lead to reactivity changes. The previous cores, Mark I and II, had fewer thermocouples.

Surrounding the fuel rods in the core are approximately 430 blanket rods made of natural uranium—2% zirconium alloy. Some blanket rods are placed in fuel assembly tubes to fill spaces not occupied by fuel rods, and others make up blanket assemblies.

Dimensions of the complete inner assembly, the part redesigned for the Mark III loading, are approximately 19 in. in length and 14⅜ in. in diam. Within this assembly the fuel rods are a composite, with the center section highly enriched and the ends natural uranium. As assembled this highly enriched center section is 8½ in. long by approximately 7½ in. in diam.

Before the meltdown EBR-I had a record of four years of reliable operation during which it produced 4,000 Mwh of heat and turned out the world's first reactor-made electricity. With its new core, EBR-I will eventually reach an operating power of 1.4 Mw(th) and an electrical output of 200 kw for a Na outlet temperature of 600° F.

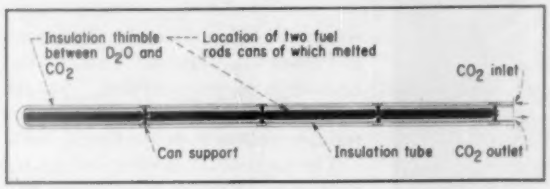


FIG. 1. Fuel channel of El2 reactor containing four fuel rods

FIG. 2. Radiograph of rod shown in Fig. 3

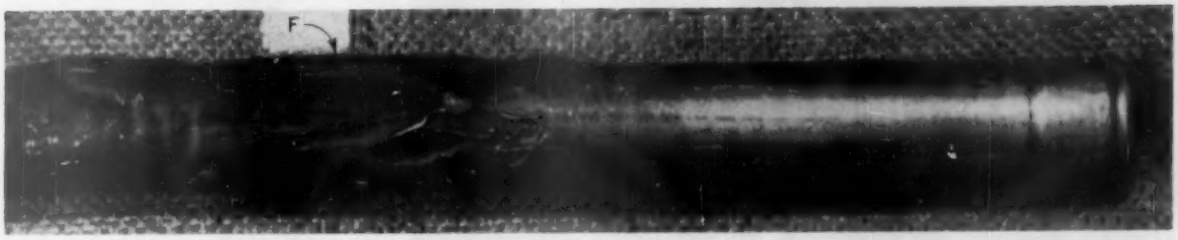


FIG. 3. El2 fuel rod showing melted magnesium cladding

Safety of Magnesium Canning for CO_2-Cooled Reactors

By MARC SALESSE
Commissariat à l'Énergie Atomique, Centre d'Études Nucléaires, Saclay, France

A fortuitous experiment made in France in El2,* the modest ancestor of CO_2-cooled reactors, supplies an encouraging indication of the safety of reactors using magnesium-canned, CO_2-cooled fuel elements.

There has been some concern during the last years about the safety of magnesium canning in CO_2-cooled reactors at 450° C.

Independently of problems that may arise from the poor mechanical properties of magnesium at high temperatures, there is a possibility of a violent chemical reaction between magnesium and carbon dioxide. For the reaction $2\,Mg + CO_2 \rightarrow 2\,Mg\,O + C$, which is one of the possible reactions, the free-energy change at atmospheric pressure is $G = -160$ kcal at 400° C.†

Oxide films, of course, may inhibit the reaction. In carbon dioxide, the oxide film is reasonably protective up to 450° C. Above 500° C, the oxidation rate increases rapidly with temperature. But, rather surprisingly, it was never possible in laboratory experiments, made in France, to set fire to magnesium below the melting point of 650° C. The ignition temperature, out of the reactor and in semistatic conditions, seems to be 800° C or more. However, there still was doubt as to what would happen in-pile under radiation, pressure and gas flow.

An involuntary experiment made in 1956 in the old El2 reactor put some light on the subject. Here is a summary of the events:‡

During the spring of 1956, anomalous temperatures in outlet-gas channel J3 were noticed. The four fuel elements of channel J3 were then removed and replaced by new ones.

Temperature oscillations were again noticed in the gas temperature of channel J3 between the 20th and the 25th of June, on which dates major temperature elevations occurred. The reactor was then shut down, and channel J3 gas-flow control gear opened.

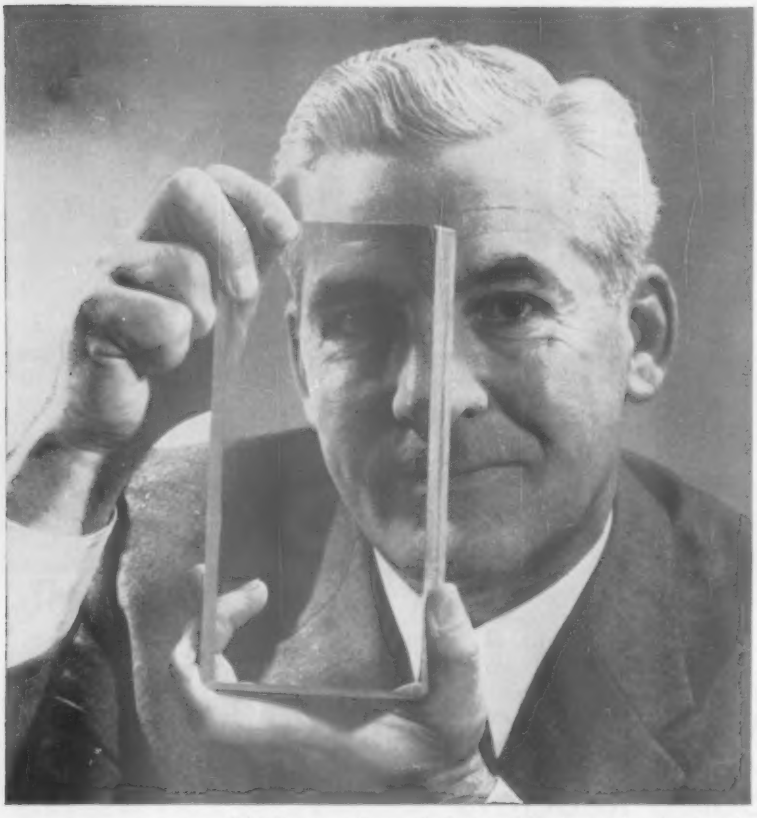
The reactor was then operated again without trouble for 20 days after June 26th and was stopped on July 16th for scheduled general refueling. During that period, definite but not very important signals were given by the leak-detection system in the gas circuit.

Later, the four 1956 fuel elements of

* El2 is a 2.5-Mw reactor cooled with CO_2 at 10 atm and a velocity of 70 meters/sec; outlet gas temperature is 120° C. Fuel elements are cylindrical rods of magnesium-canned natural uranium; maximum temperature of can is (normally) 350° C. There are four fuel elements per channel.

† M. L. Boussion et al., report MCA-417 (1957), available from Commissariat à l'Energie Atomique, Centre d'Etudes Nucléaires de Saclay, France.

‡ J. A. Stohr, "Jeu 2000 B. Cas de la barre 288," report MCA-A-40/N (1957), available from Commissariat à l'Energie Atomique, Centre d'Etudes Nucléaires de Saclay, France.



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This article starts on p. 123

channel J3 were examined. The upper and lower fuel elements, 1 and 4 (Fig. 1), were in perfect condition. But the middle rods, 2 and 3 (in a higher flux region), were as shown in Figs. 2 and 3.

The magnesium canning had melted partially. Molten magnesium had crept away (or been removed by CO_2 flow) and had later solidified around the melted area, forming cushions and drops. The radiograph of Fig. 2 shows the thickness of the magnesium cushions. It shows also the undamaged surface of the grooved uranium.

It is certainly premature to draw any definitive conclusions from such an occurrence. However, a few points appear likely and may be of some interest:*

1. Can temperature rose to 650° C since part of the magnesium melted.

2. At this temperature and flux (5×10^{12} n/cm²/sec), no important chemical reaction took place between CO_2 pressurized at 10 atm and either solid or molten magnesium.

3. The magnesium was commercially pure electrolytic magnesium and not an "unoxidizable" magnesium-base alloy.

4. At 650° C or more, uranium ought to have reacted with CO_2. The fact that there is no uranium oxidation evident in the radiograph is in good agreement with the relatively low level of contamination of the gas circuit and leads to the conclusion that a protective film must have partially protected the uranium. (Area F in Fig. 3 shows perhaps some evidence of such a film, the exact nature of which is not yet fully established.)

5. Despite the strong thermal cycling, no ratcheting occurred between the core and the clad. Thus the anchoring of magnesium by grooves in the uranium surface seems to provide a satisfactory safety margin in the presence of external gas pressure.

If such an experiment is not an erratic one, magnesium may prove to be a relatively safe canning material in CO_2-cooled reactors. As far as magnesium is concerned, temperature limitations will perhaps arise from mechanical rather than chemical considerations.

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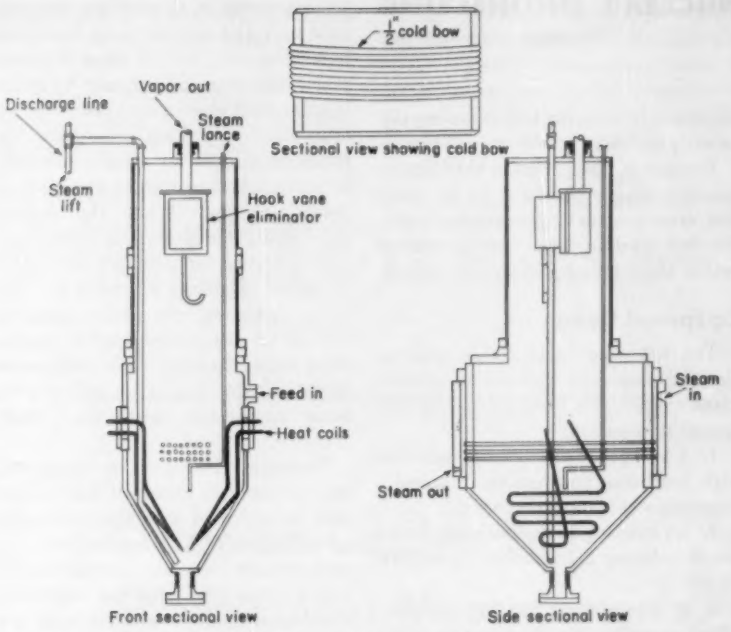
* The cause of the incident is of minor importance. It was probably a failure of the channel J3 gas-flow control system or partial stoppage of the flow by a foreign body.



EVAPORATOR configuration found most suitable for radioactive waste concentration

High-Purity Evaporator for Waste Concentration

By T. C. CARNAVOS and J. W. HAGEN
Griscom-Russell Company, Massillon, Ohio

The disposal of wastes from laboratories and facilities processing radioactive materials is a problem that promises to become more acute as the number of these installations increases. The disposal method now most commonly employed consists of containing these wastes in the alkaline state in underground water-proof tanks shielded against escape of radiation. Since these storage facilities are expensive, it is desirable to concentrate wastes as much as possible. Some of these wastes have as little as 1% dissolved solids, and evaporators are employed to concentrate these wastes to about 30% solute concentration prior to storage. The water removed during concentration, if sufficiently pure and free of radioactivity, can then be safely discharged to surface or underground streams.

Evaporator Specifications

Although storage at 30% salt content is considerably better than storing the original wastes, the storage costs are still expensive. To reduce these costs a test program was initiated looking to greater concentration. The aim of this project was to design a remotely operated evaporator to accomplish the following:

1. A threefold reduction in waste volume with concentration to 70% salt content. That is, for every 3 gal of waste, 2 gal of decontaminated water were to be produced and 1 gal of concentrated waste discharged.

2. A decontamination factor of the water vapor produced of 10^6 or better. This means that if the concentrate is to be 70% solids, the vapor should carry over <0.7 ppm of solids.

3. Operate remotely behind shielding.

4. In the event of instrumentation or power failure, be capable of being shut down and restarted after the system has cooled down and the concentrate allowed to solidify.

5. Be capable of prolonged operation

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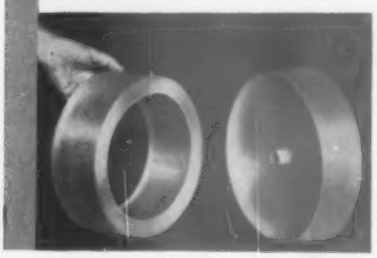

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by means of cleaning and descaling the heating surface.

Because it was expected that design modifications would have to be made and various operating techniques tried, the test medium used was simulated rather than actual radioactive wastes.

Equipment Design

The following basic design conceptions employed in high-purity powerplant evaporators were applied to this special application:

1. A low-vapor disengaging rate and high headroom to promote "natural" separation of water and vapor.

2. An efficient mist eliminator capable of reducing entrainment by factors of 10^3–10^4.

3. A bowed-tube heating section, which permits scale shedding by thermal shocking.

Two special design features incorporated in this evaporator are a bottom with sloped sides to prevent the accumulation of solids at this point, and a concentrate-discharge line located at the lowest point of the bottom. This discharge is sealed by a riser line, which eliminates the necessity for control valves or flow obstructions of any kind, the seal being accomplished by hydraulic head.

Experimental Work

Testing of this evaporator with various forms of simulated waste revealed many problems not previously appreciated. The illustration shows the evaporator configuration that resolved many problems. Additional special features developed and added during the course of the experimental program were an internal discharge line with a steam lift, internal steam lance and internal heating coils.

This evaporator system, with a few simple controls, is capable of concentrating waste, controlled manually or automatically, and lends itself to continuous or batch operation. Furthermore, if the waste has a tendency to freeze when allowed to cool to ambient temperature, this evaporator can be restarted by remote means in case of an unscheduled shutdown and accidental freezeup.

The method for starting this evaporator is quite simple. The evaporator shell is charged with waste to a level above the tube nest. Approximately 25-psig steam is allowed to enter the tube nest and internal heat coils until boiling occurs. At this point the operator feeds waste periodically to maintain the level above the tubes. As this concentration process progresses, the steam pressure to the tubes is increased to sustain boiling due to the boiling-point elevation. When the desired concentration is reached, as determined by the boiling temperature, the steam lift in the discharge is activated. For batch operation, the feed is stopped and all of the concentrate is steam-lifted out of the shell. For continuous operation, the feed is allowed to continue compatible with the design capacity.

Unscheduled evaporator shutdowns due to complete steam or feed failure were investigated with the evaporator operating at 70% concentration. As part of these tests, the system was allowed to cool to ambient condition, whereupon the shell contents froze to a solid cake. By use of the heat coils and steam lance, the system was returned to normal operating condition in about 12 hr.

One of the wastes tested scaled the heat-transfer surface extensively. In a 48-hr period, the over-all heat-transfer coefficient was reduced five-fold. With our Bentube design, it was possible to crack the scale thermally and return to normal operating conditions (i.e., 70% concentration) in 5 hr. This time is peculiar to the unit under test and could have been shortened with some redesign.

The purity of the evaporated condensate produced was measured in two ways. A salinity indicator normally used in marine work measured the impurity in grains of seasalt per gallon. This device is not considered accurate enough for high-purity condensate and served more as an indicator. Samples of the condensate and concentrate were analyzed by the sodium-tracer technique. With the eliminator being used and a waste that did not foam, decontamination factors of 10^6 were realized. A second waste that foamed excessively was tamed by adding a foam suppressor, and with the built-in evaporator headroom (but with a de-entrainer that had been heavily fouled by foam before the foam suppressant was added), DF's of 5×10^5 were obtained. These results emphasize the desirability of providing means for backwashing de-entrainers used in radiochemical service.

Finally, successful automatically controlled operation was achieved for

sufficient periods of time to indicate the feasibility of such controls.

Conclusions

The evaporator satisfactorily met the requirements. The savings achieved by boildown to high salt concentrations should readily justify the cost of the evaporator. Because the variety among radioactive wastes is likely to be great, a test program on simulated waste is advisable to discover what problems exist.

* * *

The information contained in this report was developed during the course of work under contract AT(07-2)-1 with the U. S. Atomic Energy Commission, whose permission to publish is gratefully acknowledged.

Oxide on Catcher Foils Spoils Power Measurements

By J. N. RENAKER, V. J. STRATTON and H. L. BERMANIS
Aircraft Nuclear Propulsion Department
General Electric Co., Cincinnati, Ohio

Reactor power measurements are sometimes made in critical assemblies by means of a catcher-foil technique. With this technique, precision-punched, 5-mil-thick aluminum foils are placed in close contact with 1-mil-thick pieces of uranium foil of a standard size. The aluminum catcher foil in contact with the uranium is then exposed at the point in the reactor at which the power is to be measured. The neutron bombardment produces fission fragments that are ejected from the uranium and caught in the surface of the aluminum catcher foil. These fission fragments decay mostly by beta and/or gamma emission and thus make it possible for the catcher foils to be counted in a beta proportional counter.

The count rate, when corrected for fission fragment decay and counter deadtime, is directly proportional to the number of fission fragments caught in the surface of the foil, and that, in turn, is directly proportional to the reactor specific power at that point.

In the course of making power distribution measurements in a critical assembly of recent interest, we found that inability to obtain reproducible data between duplicate runs is caused by the nonuniformity of oxide film on the uranium foils used.

Edgewise microscopic examination reveals that uranium foil, nominally one mil or 25.4 microns thick, can have an oxide film ranging in thickness from 6 to 19 microns. Because the range of fission fragments in uranium metal is approximately 7 microns, and in uranium oxide formed at room temperature is approximately 14 microns, there is a doubling in the fission fragment range and a four- to five-fold increase in the volume occupied by any given number of uranium atoms on the surface of badly oxidized specimens. Consequently, in oxidized as compared with nonoxidized fuel, fewer U^{235} atoms are effective in producing activation of the fission-fragment catcher foils.

Power distribution measurements using clean deoxidized uranium foils give reproducible data. Alternatively, one can use foils that have the same oxide from piece to piece. However, equally oxidized uranium foils cannot be selected by visual means. We recommend, therefore, that foils, even those with identical histories, be cleaned prior to use—possibly by dipping them in a hot nitric-acid bath.

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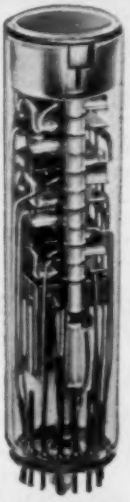

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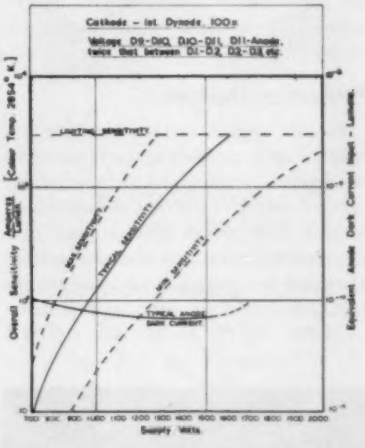
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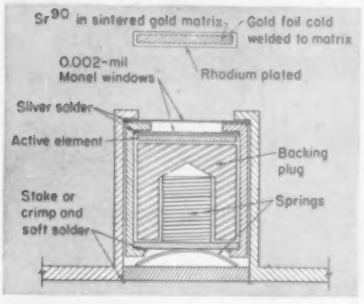
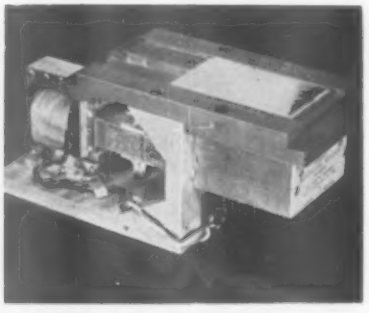


1. SOURCE CAPSULE holds noble-metal sandwich. Center is radioactive salt dispersed in noble-metal matrix

2. CARRIER retains all radioactivity in event of damage to equipment. Deformation of thread provides permanent seal



3. SHUTTER provides shielding and physical protection. Heavy spring causes rapid closure if solenoid is deenergized

Putting Safety into Gaging-Source Designs

By GEORGE B. FOSTER
Industrial Nucleonics Corp.
Columbus, Ohio

Safe use of radioactive materials in gaging operation involves protection against two hazards. One is the ingestion of radioactive materials, many of which are contained in compounds that are poisonous in their chemical nature alone. The other is external exposure to ionizing radiations.

Protection Devices

In our gaging installations we use four means to protect against ingestion: mechanical binding and encapsulation; safe mounting of the capsule; shielding, locking and alarm devices; and preventive maintenance and inspection. Distance and shielding are used to protect personnel from external exposure.

Encapsulation. The radioactive material is typically present in the form of a salt chosen for its relative insolubility in water and normal reagents. For example, in the case of Sr^{90} this is a strontium-barium sulfate. This salt is bound up in a metallic matrix of a noble metal such as gold, and the whole is encapsulated in a noble-metal sandwich that is welded or hard-soldered to a mounting plate, a cup or other carrier (Fig. 1).

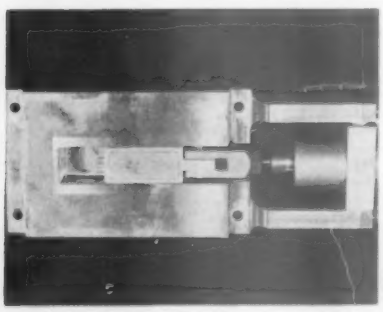
The integrity of this hermetically sealed capsule could be destroyed by heat enough to melt the steel jacketing (2,600° F) and the gold matrix. In such a case the intent is that the active material be carried along in the molten gold since the rate of sublimation of the sulfate is low and the compound does not melt and decompose until it reaches 2,800° F.

Mounting. The capsule is mounted typically in a carrier (Fig. 2), and a plug carrying a pipe thread is screwed in to complete closure.

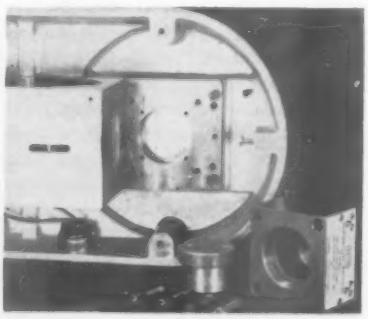
A major purpose of the carrier is to provide an ultimate unit that will contain all of the radioactivity in the event of a major disaster involving the crushing or fragmentation of the gaging equipment. The carrier is finished in a bright orange color and has highly legible lettering pertaining to its nature.

Shutters. In Figs. 3 and 4 are shown shutters designed to contain radiation and offer mechanical protection to the source when it is not in use. Figure 5 shows details of a shutter-and-carrier assembly.

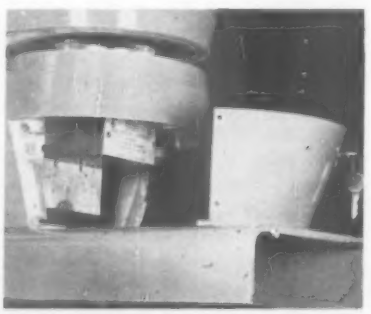
Locks and alarms. The practice of using radioactive materials in industrial environments is not old enough to ensure that operating personnel will



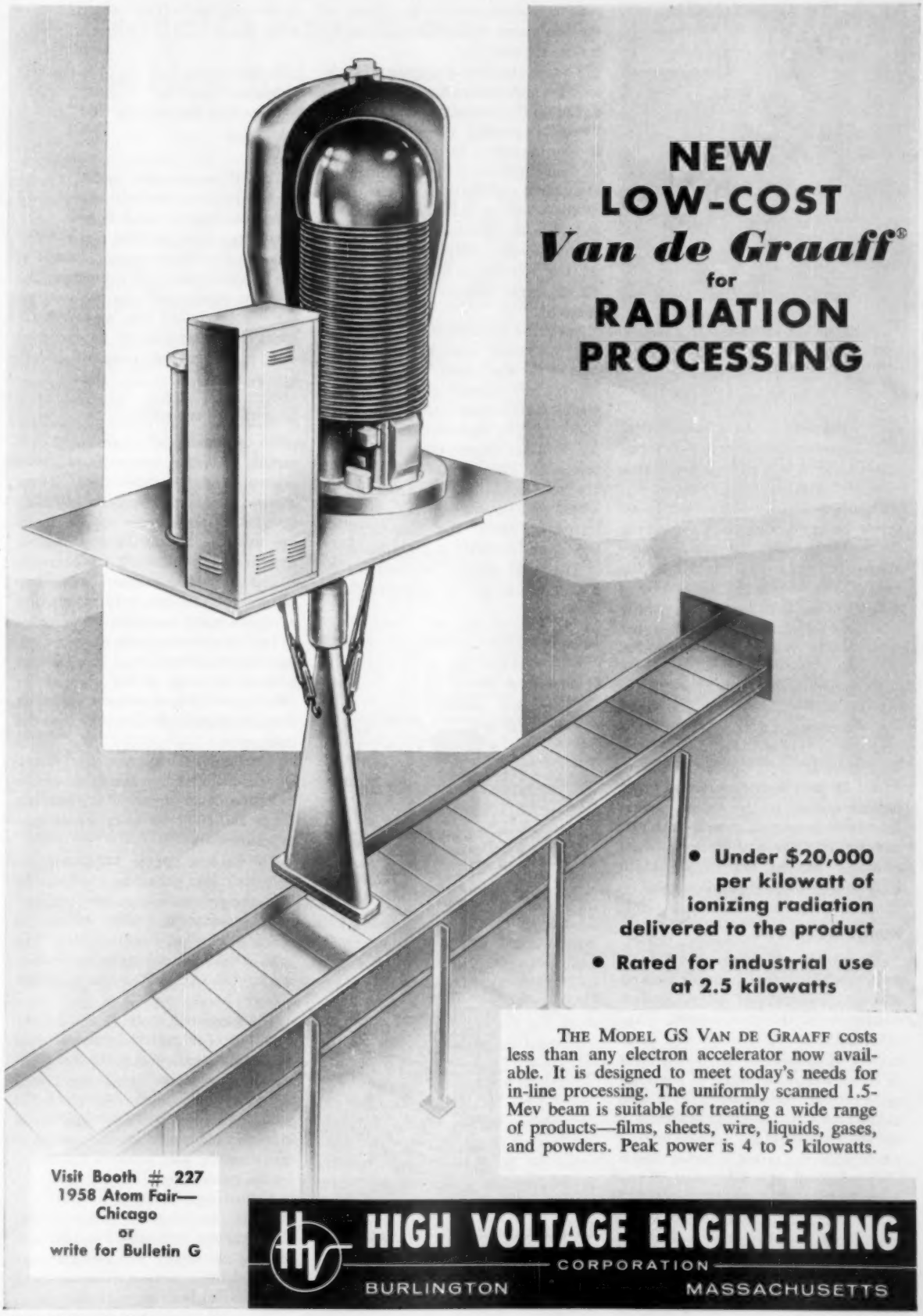
4. HEAVIER SHUTTER for rolling-mill installation is for more penetrating radiation. It has cylinder actuator



5. CARRIER AND SHUTTER ready for assembly. Subsequent operations use jigs to prevent personnel exposure



6. LOCKED COMPARTMENT houses installed source carrier. It makes up for lack of familiarity on part of personnel



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7. FUSE guards radiation-exit aperture. Breakage of conducting-paint ribbon closes shutter and sounds alarm

display the same degree of respect that they have for electric-power-distribution devices like switch boxes. This calls for locks and access covers.

Figure 6 shows a lock fitted to an access cover for the space containing the carrier. Entry through the radiation-exit aperture is prevented by the fuse of Fig. 7. Forced penetration is difficult in the first place because of the small gap between the lower and upper arms of the usual gaging apparatus (Fig. 6).

Maintenance and inspection. Failure of the encapsulation described above is unlikely. If a failure were to occur, it is thought that it would be very gradual. The initial indication would be radioactive material on the outside surface of the source carrier, detectable by wiping with a swab and monitoring the swab. Such tests are routinely carried out at six-month intervals, by either supplier or user.

Range Reduction

Absorption of radiation within a source capsule places an upper limit on effective strength of point sources employed in thickness gaging. Another effect is the generation of beta-excited X-radiation. In installations in which this is the mode of measurement the only consideration is the ratio of the bremsstrahlung flux produced in the source matrix and capsule to that produced in the target material chosen to produce a desired mean X-ray energy.

However, when beta absorption or reflection is the chosen mode of measurement, the presence of an excessive bremsstrahlung background significantly reduces the signal-to-noise ratio and decreases the sensitivity of the equipment when ion-chamber detectors are used.

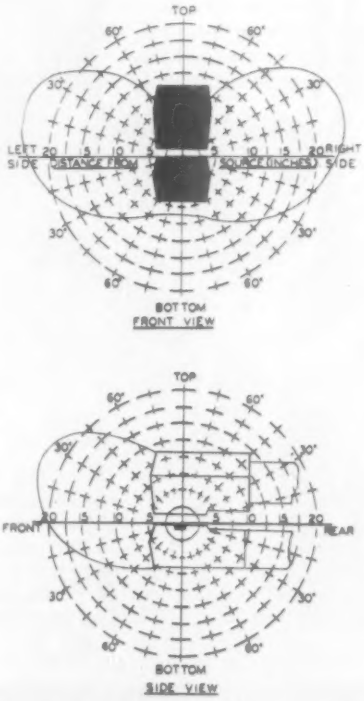
The protective-diaphragm technique, which carries an electric circuit right into the primary beam, imposes a "weight" penalty of ~100 mg/cm². It also imposes a further requirement on the equipment designer. Since this absorber lies in the most critical region of the whole source assembly from a source-geometry standpoint, any variation or change in the physical characteristics or orientation of this diaphragm causes severe changes in the emergent spectrum.

Spectrum changes cause changes in the calibrated absorption characteristic of the equipment. Reproducibility of this characteristic is one of the most important reasons why radioisotope gaging equipment has achieved its rapid acceptance for process measurement. Manufacturing methods of the highest caliber are required to assure that these considerations do not adversely affect the long-term accuracy and stability of the equipment.

The total penalty imposed on the maximum range of measurement is ~400 mg/cm². This absorption is made up of:

Source matrix	175 mg/cm²
Source "windows"	125
Protective diaphragms	100
Total	400

For Sr^{90} sources this results in a reduction by about 60% of the theoretical maximum range of measurement. For low-energy beta emitters this penalty becomes even more severe. However, the lessened range of equipment application is accepted as a performance penalty much like the "reserve-fuel" requirement established by commercial air carriers for passenger-aircraft operations.



8. RADIATION CONTOUR is measured as soon as assembly is completed. It helps in design of safety precautions in both further manufacture of gage and eventual permanent installation

Shielding Inspection

On completion of an assembly containing an active source its radiation contour pattern is determined. These measurements are made with both integrating-ion-chamber and G-M survey instruments, as appropriate. A typical result is shown in Fig. 8.

The radiation contours have two purposes. The first is to ensure that adequate safety measures are provided in further manufacturing of the gaging equipment. The second is to permit advance planning of any shielding or other operator protection required in the permanent installation site for the equipment.

A radiation contour of the closed-shutter condition is omitted because the radiation level in every instance is below the 40-hr-per-week continuous-exposure limit.

The isodose curves vary considerably from one design to another. In beta-absorption equipment primary-beam collimation greatly affects the position of the 7-mr/hr line. The greater the collimation the less scattering is evident, and the closer lies the 7-mr/hr line.

The measured contours are for the condition of no material present in the measuring gap. When the manufacturing process on which the gaging equipment is installed is operating, the radiation level on the 7-mr/hr contour is greatly reduced in intensity owing to the shielding and absorption afforded by the process itself.

A further measure of protection is afforded the process operator in that the ordinary industrial hazards from moving machinery and the processed material itself make a close approach to the gaging head impractical.

Radiation Applications in New York Industry

By ALBERT P. ABRAHAMS
New York State Department of Labor
New York, New York

Industrial radiation installations in New York State must be registered with the Division of Industrial Hygiene of the state Department of Labor. These installations include those that use radioisotopes, X-ray generators, particle accelerators and nuclear reactors and handle nuclear fuel materials.

Table 1 lists registered uses of radionuclides. Table 2 is a breakdown of the 3,130 radiation-producing units that are currently registered. They belong to 262 owners at 320 locations. The list offers an interesting opportunity to see where and how nuclear techniques are being used in a typical industrial state. Its primary purpose, however, is to aid in limiting the hazards of these installations.

The second half of Table 2 shows the types of sources that make up the 40,242 curies of radioisotopes registered in the state. They include high-level radiation sources as well as the low-level supplies of radioisotope laboratories. Not included is a considerable quantity of classified fissionable and fertile material. In Table 3 is a list of registered installations by industry.

Geographical Distribution

Distribution of installations is not uniform. Industrial X-ray units are found in large numbers in Schenectady, Rochester, Buffalo and the metropolitan New York area. Radioactive static eliminators are found in greatest numbers in New York City's printing, publishing and photography trades. The radium industry is confined almost entirely to New York City. Unsealed isotopes are predominantly associated with large corporate research laboratories, as are sealed sources in the kilocurie category. Sources of 0.1–10 curies are concentrated in heavy-industry areas where they are used for testing and quality-control purposes.

X-rays. From the standpoint of number registered, the most prominent high-hazard sources are industrial X-ray generators. They have wide applications where metals are cast, fabricated or welded. X-ray examination of metal parts, welds, etc., is not routine in all plants but is characteristic of those doing the highest-quality work and those having defense contracts for aircraft and tank production, etc., in which the federal government requires it. X-ray units for this purpose range from 100 to 1,000 kv.

Industrial fluoroscopy in New York is confined to a few places performing routine examination of organic materials such as food and plastics for metallic impurities. X-ray units in the 35–70-kv range are used increasingly in diffraction and fluorescence analysis. X-ray gages are widely used to measure the thickness of metals.

Radioactive static eliminators are used widely wherever a mat or web of fibrous organic material can accumulate quantities of static electricity by friction—notably textile, paper and printing industries. The most commonly used ones are metal bars on which a thin layer of radium or polonium has been deposited and then sealed by an additional electroplated layer or other means. These devices eliminate the fire hazard of sparking discharges and improve register in multicolor printing. Radioactive brushes are used for dusting phonograph records and photographic films.

Isotopic Sources

Small sealed sources are the most numerous type of radioactivity installation. They are used in calibrating and checking radiation-measuring instruments, as ionizers in spark gaps, thyratrons, fluorescent lamps and other gas-filled electronic tubes, wave guides and similar devices, and as phosphor activators. Two plants in the state are also making nuclear batteries.

Large sealed sources are used principally for radiography and irradiation. Multicurie sources of Co^{60}, Ir^{192}, Tm^{170} and other suitable gamma emitters are used for radiography of pipe lines, pressure vessels and other fabricated metal products of such shape or thickness as to make X-ray use uneconomical.

With few exceptions unsealed isotopes are used in less-than-curie quantities as experimental tracers in research projects. Applications to

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TABLE 1—Number of Installations Using Radioactive Materials*

Nuclide†	Neutron sources	Static eliminators	Radium processing	Unsealed tracer	Sealed irradiation source	Beta gage	Sealed calibration source	Sealed radiographic source	Density, vacuum & humidity gage	Activated material	Luminous dials	Fuel-element fabrication	Ore	Nuclear reactor	Fissionable material	Waste	Metal & glass production	Analytical chemistry
Po^{210}	5	17	1	4	1													
Sr^{90}				4	10	24	7											
Ac^{227}			1															
Sb^{124}				1														
As^{77}				1														
$Cs^{134,137}$				4	3	4		2	4									
Cl^{36}				4														
Co^{60}				12	23		10	22	5							1		
$Fe^{54,55,59}$				6			3			4						1		
Pb^{210}			1					1										
$Mn^{52,54}$				1														
Ni^{63}				7	2											1		
$Ra^{224,226}$	9	61	5	4	9	2	28	3	45		11							
Ru^{106}				1			1											
Sc^{46}				1														
$Ag^{105,110}$				5	1													
Tc^{99}				2														
Ca^{45}				3														
$I^{131,128}$				7	1		1											
Ir^{192}								7										
Mo^{99}				1														
P^{32}				7	1		1											
Pm^{147}				1		2												
$Br^{80,82}$					1													
Sm^{153}				1														
Na^{24}				1														
Sn^{113}				1														
K^{42}				1														
$W^{187,185}$				2														
Cd^{115}				1														
Zn^{65}				2														
C^{14}				21		2	2											
Cr^{51}				2														
$Ge^{71,77}$				2														
S^{35}				12														
Tl^{204}				2	1	8												
Tm^{170}								1										
H^3				9	2		1				1							
$Th^{230,227}$			1	2								2					4	1
$U^{238,235}$				2	1		1					7	3					3
Bi^{210}			1	1														
Hf^{181}							1											
Kr^{85}					2	1												
Hg^{203}				2														
Nd^{147}				1														
Si^{31}				1														
Zr^{95}				1														
Unspecified				1			3			1				3	5	3		

* In New York State as of September 15, 1957.
† Nuclides are arranged in order of decreasing toxicity.

production have been slow to develop so far.

Small neutron sources are increasing in use for reactor startup, activation analysis and the calibration of neutron survey meters.

Radium. The radium industry is a special case since radium and its various daughter products are commercially available without AEC license. A few large sealed radium sources are still in use for industrial radiography, but artificial isotopes are steadily supplanting them. Nearly a dozen plants are still engaged in painting watch and instrument dials with radium-activated luminous paint. A few others are involved in recovering radium, preparing therapeutic implants, making sealed sources and paints, etc. The World War II peak of 50 plants and 1,000 workers is now reduced to 15 plants and 50 workers.

TABLE 2—Radiation Sources by Type and Strength*

Radiation Producing Equipment	*Number*
Industrial X-rays	356
Static eliminators	1,607
Diagnostic X-rays	131
Radioactive gages†	220
High-voltage thermionic equipment‡	785
Particle accelerators	15
Neutron sources	9
Nuclear reactors	7
Total	3,130

Radioactive Materials	*Quantity (curies)*
Small sealed sources (<1 curie)	13.718
Large sealed sources (≥1 curie)	34,100.930§
Unsealed isotopes	6,059.181
Radium and daughter products	3.169
Unsealed uranium and thorium	5.760
Activated materials	0.570
Fission products and other waste	59.051
Fissionable material	¶
Total	40,242.379

* Source: M. Kleinfeld, "Administrative Experience with New York State Industrial Code Rule 38: Radiation Protection."

† Density, thickness, vacuum and level gages.

‡ Electron microscopes and diffraction apparatus, theater projection television, power supplies, magnetrons, klystrons and other electron tubes operating at 16 kilovolts or more.

§ Includes one single source of 25,000 curies.

¶ Quantity classified for national security.

TABLE 3—Installations by Industry*

Industry	*Installations*
Mining	3
Manufacturing	
Stone, clay and glass	19
Primary metals	32
Fabricated metals	50
Machinery, nonelectrical	37
Machinery, electrical	69
Transportation equipment	39
Instruments	76
Food	4
Textile mills	22
Apparel	4
Paper	21
Printing and publishing	34
Chemical	93
Petroleum and coal	11
Rubber	7
Leather	2
Miscellaneous products	15
Public utilities	23
Wholesale and retail trade	5
Service industries	33
Research	62
Not otherwise classified	3

* Source: M. Kleinfeld, "Administrative Experience with New York State Industrial Code Rule 38."

Fuel Production

In the field of nuclear fuel production New York State has one operating uranium mine and two fuel-element fabricators. The mine and its associated processing mill are in the Ramapo Mountains. Promising ore samples and the geology and economics of the situation indicate that there will someday be a going uranium-mining industry in the East.

Registration of radiation installations is one of several steps that the New York State Department of Labor is taking to anticipate difficulties that can arise in the increasing use of nuclear technology. There are few difficulties with large installations that have the means and personnel to administer their own programs effectively. More risk is threatened where people who are unfamiliar with radiation devices are using them. We intend to find and remedy such situations before they become hazardous.

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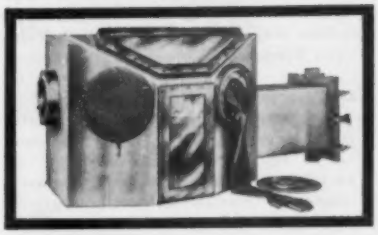

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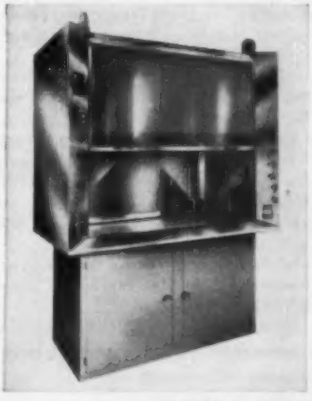

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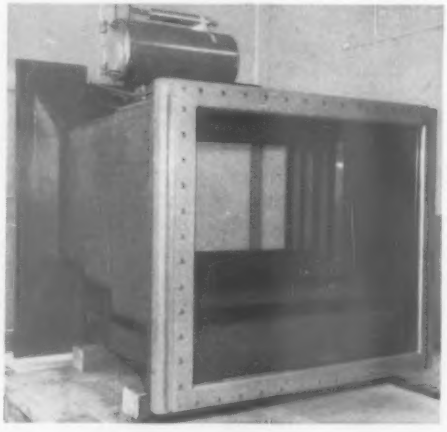

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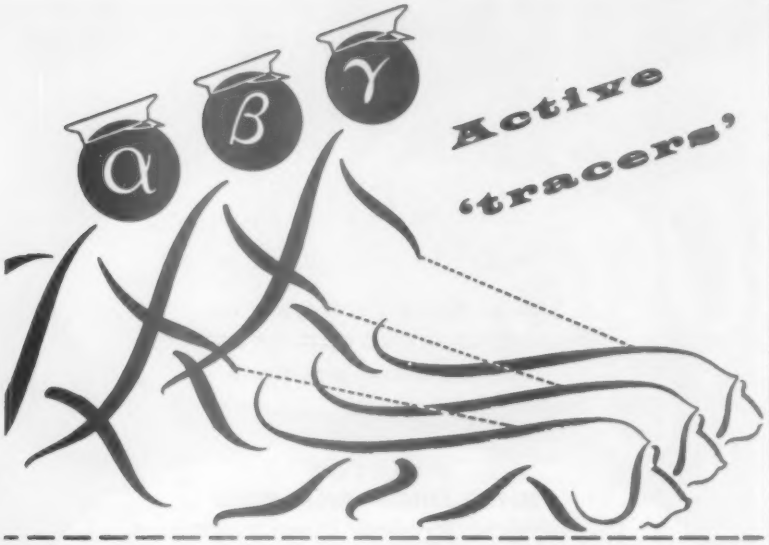

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Phenothiazine-S35
Di-*iso*propyl fluorophosphonate-P32
Tetraiodophenolphthalein-I131
4-Iodoantipyrine-I131
Iodinated oils and fats-I131
Mersalyl-Hg203
Sodium stibogluconate-Sb124

Surface-active Agents :
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Sodium di-*iso*amyl sulphosuccinate-S35
Sodium lauroylmethyltauride-S35
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Chemical Reprocessing—II

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Atomic Energy Management Conference Panels

Monday, 9:30 a.m.—12:00

Health and Safety. Discussion of what needs to be done to solve some of the unique health and safety problems in atomic energy development.

An Industry Assessment of the U. S. Power-Reactor Program. Discussion will center upon the adequacy of our program for civilian nuclear power development. The main question to be raised will be: Is this program consistent with our objectives of maintaining world leadership in nuclear technology and the development of a vigorous atomic industry?

Selling Nuclear Products Outside the U. S. This panel will attempt to define the foreign market potentials in the atomic energy field.

Are Small-Reactor Units Economically Feasible? The potential markets for this type of power plant will be explored with the economics and design characteristics of the more promising small reactors.

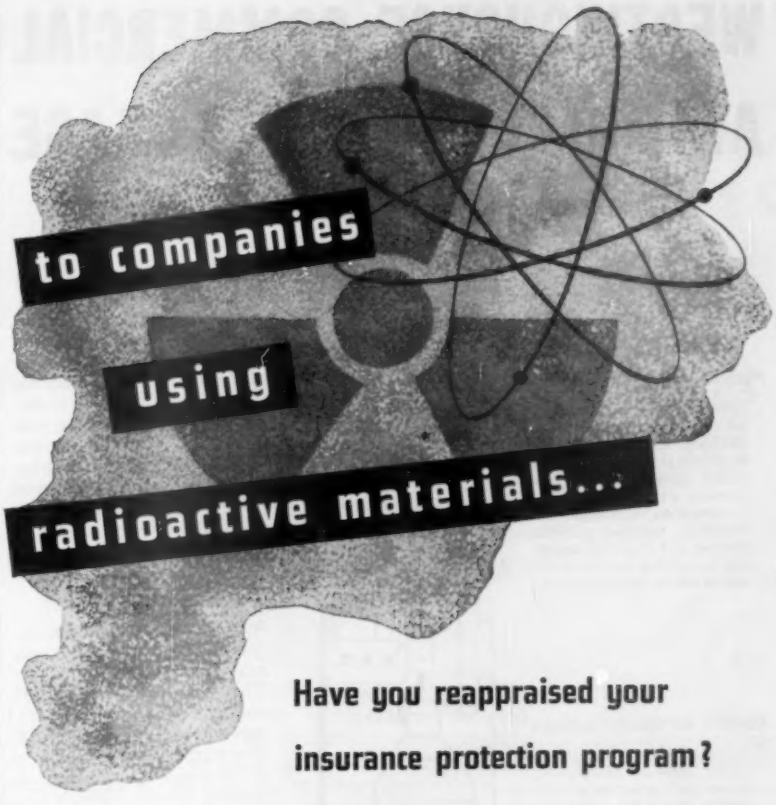
Monday, 2:30—5:00 p.m.

Power-Reactor Experience. An evaluation will be made of the experience to date of the five different power reactor prototypes that were operated in the past year. What is being learned that will aid in the design and operation of truly large-scale reactor power plants will be covered.

Should the Atomic Energy Act be Amended? Certain features of the Act, in effect for three and a half years, will be reviewed. There are recommendations pending that some of its restrictive limitations be relaxed.

Outlook for Nuclear Ship Propulsion. This session will report on our ship propulsion program as initiated jointly by AEC and the Maritime Administration. Future developments in this phase of the atomic energy program will be considered.

Market Potentials for Atomic Materials Outside the Nuclear Field. Material costs



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Chemists and Chemical Engineers

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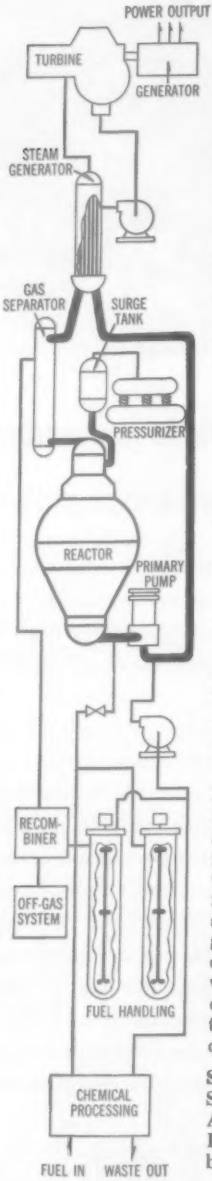
Mechanical Engineers

Design high pressure piping and vessels, heat exchangers, remote repair equipment and tools, gas handling equipment, mixer mechanisms; analyze problems in fluid flow, heat transfer, erosion, corrosion, gamma heating, stress analysis, hydraulic design, valve development, fluid dynamics, instrumentation and control.



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FIRST IN ATOMIC POWER

NUCLEAR CONGRESS

This article starts on page 77

must be reduced if nuclear power costs are to be cut down. One way to accomplish this is to find new markets for the materials in non-nuclear areas. This panel will discuss progress made in finding markets for nonnuclear uses of nuclear materials. Estimates of how this will affect the reduction of nuclear costs will also be covered.

Tuesday, 9:30 a.m.—12:00

How to Develop Better Products Through Radioisotopes. How radioisotopes can be used profitably will be the subject; experts in the field will present their solutions to the problems encountered in this field.

Reduction of Nuclear Power Costs. Substantial reductions must be made both in capital and operating costs. Answers to this problem will be attempted by considering the following: improved techniques in the manufacture of reactor components, cheaper methods of shielding and containment, and proper instrumentation.

Materials Testing Facilities—Supply and Demand. Manufacturers of reactor components and materials must have facilities for testing their products under actual reactor operating conditions. The types of test reactor facilities needed, those presently available, the techniques of arrangement for use and the problem of priority service will be covered.

How the Indemnification Law is Working. This panel will discuss how the new law is working, the problems that have arisen in the procurement of private protection and the status of financial protection against the liabilities assumed in overseas sales.

Tuesday, 2:30—5:30 p.m.

Latest Prospects for Economic Nuclear Power. Some of the problems to be explored will be the prospects for achieving economic nuclear power for second generation plants and the number of generations of nuclear plants expected to be built by industry and/or government.

Potential Applications for Large Sources of Radiation. In the petroleum and chemical industries, industrial applications of large sources of radiation seem promising. Product improvement, lower costs of some processes, and the creation of new products will be the result if such uses prove feasible. Applications for large sources that are currently being considered will be discussed, as well as their industrial significance.

Latest Developments in Thermonuclear Research. Scientific efforts have been directed recently toward the control of the thermonuclear process. The prospects and timetable for producing controlled thermonuclear power will be considered.

Economics of the Reactor Fuel Cycle. Fuel fabrication and reprocessing are areas in which substantial reductions in cost might be achieved. However, such reductions on a supply and demand basis are hindered because of government control on lease charges for fissionable materials and on buy-back prices for plutonium and U^{233}. This panel will attempt to define those areas of the fuel cycle that, through further development technologically, may be subject to real economies in the future.

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Wednesday, 9:30 a.m.—12:00

International Atomic Energy Activities. The atomic energy program set forth in the Euratom target is the largest single market for sales by U. S. manufacturers outside the United States. Administrative problems, such as assistance through individual bilateral agreements with specific countries or agreements with multi-country organizations, will be considered by U. S. and non-U. S. experts.

Hot Lab Papers

Wednesday, 9:00 a.m.—12:30

Hot Cells and Process Facilities

New Multicell Facility in Idaho—D. C. Durrill, R. D. Dwigans, GE-ANPD

Modified Hot Cell Facility at Livermore, California—R. V. Steele, V. P. Treciokas, Pratt & Whitney

Remote Metallography at Pratt & Whitney Aircraft Livermore Hot Cells—E. C. Ward, A. J. Passeri, R. M. Hawkins, A. C. Loethen, W. Kinder

Hot Machine Shop Cell at Pratt & Whitney Aircraft Livermore Facility—C. E. Cunniff, Jr.

Segmenting Cells for Dismantling in Reactor Experiments—T. A. Arehart, J. A. Kaserman, T. L. Trent, ORNL

New Chemistry Cell and Hot Waste Disposal System at the Knolls Atomic Power Laboratory—L. A. Altamari, R. F. Stearns, GE-KAPL

Design for a Remotely Operated Facility for High Temperature Processing of Spent Reactor Fuel—G. J. Bernstein, J. Graae, M. Levenson, J. H. Schraidt, ANL

Equipment for Purification of Spent Reactor Fuel by Melt Refining—D. C. Hampson, R. F. Malecha, J. H. Schraidt, ANL

Shielding Window Design for the EBR-II Process Plant—K. R. Ferguson, L. M. Safranski, ANL

Analytical Junior Cave Facility for EBR-II—M. Levenson, J. J. McCown, ANL

Megacurie Cave for Metallurgical Testing—W. B. Doe, ANL

The Manipulator Hot Cells Above the ORR Pool—H. M. Glen, ORNL

Wednesday, 2:00—4:00 p.m.

European Hot Laboratories

A 10 Kilocurie Hot Laboratory in Saclay—Bazire, Duvaux, Blin, Cherel, Saclay, France

Equipment and Radio-Chemical Techniques in Saclay's Hot Laboratories—A. Raggenbass, J. Dufresne, P. Faugeras, Saclay, France

Equipment and Radio-Metallurgical Techniques in Saclay's Hot Laboratories—J. L. Bernard, G. Cherel, J. P. Mustellier, P. Bussy, D. Gondal, J. Bloch, Saclay, France

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Some Ideas and Proposals Regarding Standardized Equipment for Hot Laboratories and Remote Control—G. W. Oetjen, Leybold-Hochvakuum-An Lagen, G.M.B.H., Koln-Bayental, Germany

Thursday, 9:00 a.m.—12:30

Irradiation and Other Facilities

The University of Minnesota Gamma Irradiation Facility—H. S. Isbin, R. O. Wollan, C. R. Lagerquist, Univ. of Minnesota

Description of a 19.5 Kilocurie Co^{60} Source and Hot Cell—R. Anliot, Admiral Corp.

Facility to Study the Effects of Radiation on Petroleum Processes and Products and the Uses of Radioactive Material in the Petroleum Industry—R. J. Buehler, Sinclair Research Laboratories

The Construction and Startup of a 100,000 Curie Co^{60} Irradiation Facility—L. W. Haaker, C. A. Hermanson, Nucledyne Corp.

A Survey of the Characteristics of Gamma Irradiation Facilities—K. R. Ferguson, ANL

The Design of the Idaho Expended Core Facility—C. E. Langlois, Westinghouse

Reactor Core and Fuel Element Handling and Disassembly in the ECF Water Pits—N. J. Clayton, Westinghouse

Operating Experience with Zinc Bromide Shielding Windows at the Knolls Atomic Power Laboratory—R. F. Stearns, E. L. Shirley, GE-KAPL

Remotely Cutting and Canning Core Samples Obtained from Underground Nuclear Tests—B. F. Bottenfield, L. M. Howell, ORNL

Portable Shielded Vehicle—R. F. Morand, GE-ANPD

The Argonne High Level Gamma Irradiation Facility—H. G. Swope, ANL

A 10,000 Curie Co^{60} Irradiation Facility for Chemical Research—R. A. Blomgren, ANL

A Gamma Irradiation Cell for Industrial Use—R. J. Moffett, AECL

Coloration of Shielding Window Glasses—K. R. Ferguson, R. L. Reed, ANL

Clarification of Clouded Oil Filled and Zinc Bromide Shielded Windows—G. G. Plastino, GE-ANPD

Hot Laboratory Practices and Equipment

Remote Metallography Practices at Battelle's Hot-Cell Facility—A. W. Hare, A. A. Bauer, R. F. Dickerson, BMI

Remote Metallographic Equipment and Practices—F. M. Cain, F. O. Bingman, Westinghouse

Micromanipulator For Use Inside a Remote Handling Cell—J. G. McCubbin, A. S. Bain, AECL

Impression Molding of Radioactive Elements—W. F. Niebuhr, H. K. Ruhl, GE-KAPL

Density Measurement Problems in Hot Cells—K. Stratton, Westinghouse

Primary Containment For High Level Cave Experiments—G. J. Deily, C. K. Nicholson, DuPont-Savannah River

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Hot Laboratory Problems in Isolating Gram Quantities of Transplutonium Elements—C. H. Youngquist, P. R. Fields, ANL

Laboratory Equipment for the Collection of Fission Product Gasses From Irradiated Ceramic Fuel Elements—R. L. Brandt, C. G. McCormack, GE-HAPO

Modification to Master-Slaves at Bettis Hot Laboratory—E. H. Stearns, Westinghouse

Remote Installation and Removal of Hot Cell Apparatus—M. G. Willey, ORNL

Fuel Recovery From Core Meltdown of EBR-I (Movie), ANL

A Conducting Plastic for Metallographic Specimen Mounts—D. C. Durrill, GE-ANPD

A Furnace for Elevated Temperature Tensile Testing—E. D. Grazzini, Westinghouse

A New Fuel Element Annealing Facility at Knolls Atomic Power Laboratory—R. F. Stearns, R. Markman, GE-KAPL

The Bettis Plant Radioactive Sample Corrosion Test Facility—A. L. Maharam, Westinghouse

A Remotely Operated Universal Milling Machine for a High Level Radioactive Metallurgy Cell—C. A. Baumgartner, Curtis-Wright

Evolution of Remote Milling Machines at Pratt-Whitney Aircraft, Livermore—C. E. Cunniff, Jr., Pratt & Whitney

Remote Controlled Lathe—C. A. Crawford, A. S. Bain, AECL

A Continuously Recording Micrometer-Profilometer For Hot Laboratory Application—K. Stratton, Westinghouse

General Electric's Vallecitos Laboratory Hot Metallographic Facility—J. R. Morgan, D. E. Hughes, GE-APED

Contamination Control Procedures at Pratt & Whitney Aircraft's Hot Laboratory, Livermore, California—M. K. Wu, H. M. Clokie, Pratt & Whitney

Decontamination Studies on Ceramic Products—A. J. Beccasio, P. Y. Feng, Armour Research Foundation

Control of Radioactive Contamination—W. H. Leith, DuPont-Savannah River

Plutonium Irradiation—W. M. Cashin, L. A. Altamari, GE-KAPL

Recovery of Gaseous By-Products Employing Vacuum Techniques—V. G. Scotti, Pratt & Whitney

Sampler and Filter Cartridge Changer Equipment for Radioactive Organic-Aqueous Streams—W. A. Pate, E. L. Hutto, ORNL

A Pneumatic Carrier for Irradiation of Materials in [NRX Reactor—E. C. Trapp, AECL

A Vacuum Dilatometer for Linear-Thermal Expansion Determination on Irradiated Materials—H. W. Deem, J. E. Gates, BML

Design, Standardization, Cost and Source of Plastic Glove Rings—O. J. DuTemple, H. O. Smith, J. H. Schraidt, ANL

Thursday, 2:00—4:00 p.m.

The Operational Aspects of Hot Laboratories—Panel

The panel discussion will consider design and operational problems in handling radio-

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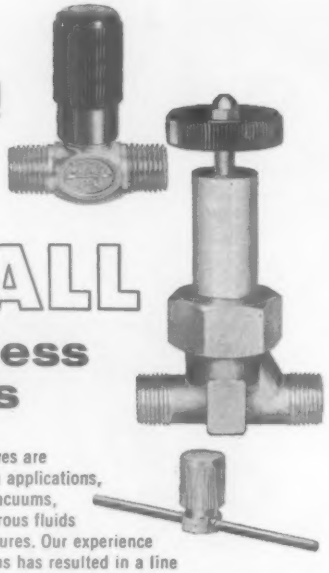

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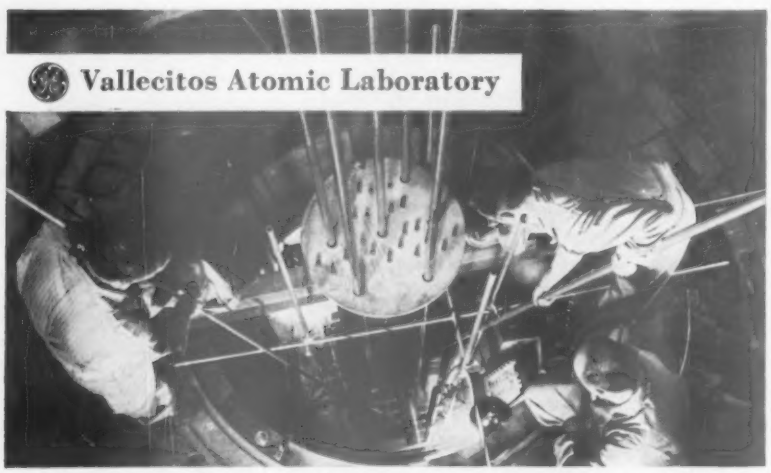

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NUCLEAR CONGRESS

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active material of greater than kilocurie activity. Panel: R. C. Westphal, Westinghouse, chairman, K. Stratton, Westinghouse, vice-chairman, E. J. Deily, DuPont-Savannah River, W. B. Doe, ANL, R. R. Fouse, Westinghouse, D. D. LaRocque, GE-KAPL, E. S. Schwartz, ORNL, L. D. Turner, GE-HAPO

Friday, 9:00 a. m.—12:30

Hot Laboratory Safety

Fire Protection and Safety Consideration for Hot Laboratories—E. L. Stout, LASL

Fire Protection in Radiochemical Facilities—T. W. Hungerford, ORNL

Hot Lab Safety—J. T. Conboy, S. C. Smith, GE-KAPL

Some Safety Recommendations Pertinent to Hot Laboratories—L. G. Stang, Jr., BNL

Laboratory Ventilation—R. J. Hale, DuPont-Savannah River

Review of High Efficiency Air Filters—P. M. Engle, Cambridge Filter Corp.

Ventilation Enclosures for Radiochemistry—R. E. Wallace, J. L. Murrow, Univ. of California

1958 Atomfair Exhibitors

(This listing contains all exhibit descriptions available as NUCLEONICS *went to press as supplied by the exhibit manager. Some listings, received late, appear at the end. The numbers are International Amphitheater booths.)*

ACF Industries, Inc., 508 Kennedy St., N.W., Washington 11, D. C. Displays of reactors and nuclear products. (100, 102)

American Association for Advancement of Science, 11 W 42nd St., N. Y. 36, N. Y. (414)

Assembly Products, Inc., Chesterland, Ohio. Temperature and voltage controls, relays and panel meters. (228)

Atomic Development Mutual Fund, Inc., 1033 30th St., N.W., Washington 7, D. C. (311)

Atomic Energy of Canada, Ltd., P. O. Box 93, Ottawa, Ontario. Irradiators, radiology machines. (401)

Atomics International Div., North American Aviation, Inc., P. O. Box 309, Canoga Park, Calif. Power reactor models. (116, 118)

Automatic Switch Co., Hanover Rd., Florham Park, N. J. Solenoid operated valves, pressure operated valves, automatic transfer switches. (349, 353)

NUCLEAR CONGRESS

This article starts on page 77

The Babcock & Wilcox Co., 161 E. 42nd St., N. Y. 17, N. Y. Reactors and fuel elements. (219, 221, 223)

Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass. Instrumentation for radioactivity detection and analysis. (210, 212)

Bendix Aviation Corp., 3130 Wasson Rd., Cincinnati 8, Ohio. Multichannel pulse-height analyzer, nuclear density gage, dosimeters and dosimeter chargers. (150)

Beryllium Corp., P. O. Box 1462, Reading, Pa. Be metal, chemicals and alloys. (320)

BJ Electronics, Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif. Spectrometry, counting, reactor-control and research instrumentation. (154)

Brush Beryllium Co., 4301 Perkins Ave., Cleveland 3, Ohio. Pure Be metal and BeO fabricated shapes. (444)

Bureau of National Affairs, Inc., Washington, D. C. Atomic industry reports.

S. Blickman, Inc., 536 Gregory Ave., Weehawken, N. J. Fume hoods and safety enclosures for handling radioactive materials and other hazardous substances. (232)

Cambridge Filter Corp., 738 Erie Blvd., E. Syracuse 3, N. Y. Filters and smoke demonstrator. (411)

Carborundum Metals Co., Niagara Falls, N. Y. Zirconium. (447, 449)

Carpenter Steel Co., Springfield Rd., Union, N. J. Stainless steel pipe and tubing, high alloys with special emphasis on a new product for nuclear power. (114)

Central Research Laboratories, Inc., Red Wing, Minn. Master-slave manipulators. (328)

Charleston Rubber Co., Stark Industrial Park, Charleston, S. C. Neoprene and synthetic rubber, dry-box gloves, chemical resistant gloves and aprons. (238)

Cleveland Hard Facing, Inc., 3047 Stillson Ave., Cleveland 5, Ohio. Steel valves, sleeves, shafts and seats with hard-faced overlays. (123)

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Columbia-National Corp., 70 Memorial Dr., Cambridge 42, Mass. Zirconium. (427)

Combustion Engineering, Inc., 200 Madison Ave., N. Y. 16, N. Y. Nuclear reactor systems, cores, heavy components, and steam generators. (313, 315)

Cooper Alloy Corp., Bloy St. & Ramsey Ave., Hillside, N. J. Stainless steel valves, fittings and castings for nuclear service. (309)

Cooper Metallurgical Associates, Box 3991, Cleveland 20, Ohio. Boron and Borides. (452)

Corning Glass Works, P. O. Box 544, Corning, N. Y. All-glass radiation shielding window, dosimeter glass and glass pipes. (202, 204)

Crane Co., 836 S. Michigan Ave., Chicago 5, Ill. Specialized piping products. (249, 253)

Crossroads Marine Disposal Corp., 26 T. Wharf, Boston, Mass. (424)

Cuno Engineering Corp., South Vine St., Meriden, Conn. Filters, edge-type, wire-wound, fiber-cartridge, porous sintered stainless steel, and screen-type for liquids and gases. (205)

Edlow Lead Co., 729 Bank St., Columbus 16, Ohio. Disposal containers for radioactive waste, lead shielding items, lead bricks, isotope shipping casks and lead castings. (236)

Edward Valves, Inc., 1200 W. 145th St., East Chicago, Ind. Stainless-steel valves. (217)

Encyclopaedia Britannica, 400 W. Madison Ave., Chicago, Ill. New edition of encyclopaedia, supplement and research services. (129)

Ford Instrument Co. Div., Sperry Rand Corp., 31–10 Thomson Ave., Long Island City, N. Y. Controls and related equipment for nuclear application. (319, 321)

General Electric Co., One River Rd., Schenectady, N. Y. Working models of reactor equipment. (405, 409)

General Mills, Inc., 1620 Central Ave., Minneapolis 13, Minn. Remotely controlled manipulators and related handling equipment. (254)

Griscom-Russell Co., Massillon, Ohio. Models of liquid metal heated

steam generator, feedwater heater, evaporator and various samples of extended heat transfer surfaces. (305)

Hamner Electronics Co., Inc., P. O. Box 531, Princeton, N. Y. Electronic instruments. (224)

High Voltage Engineering Corp., Burlington, Mass. Van de Graaff and microwave linear particle accelerators for nuclear research, electron processing, sterilization and radiation chemistry. (227)

Industrial Accessories Corp., P. O. Box 127, Glen Ellyn, Ill. Zinc bromide window, special sodium vapor light fixture and air filters. (415)

International Nickel Co., Inc., 67 Wall St., New York 5, N. Y. Use of nickel and nickel alloys in atomic energy. (113, 115)

O. G. Kelley & Co., 98 Taylor St., Dorchester 22, Mass. Various types of radiation shielding and stainless steel equipment for the nuclear industry. (220, 222)

Kollmorgen Optical Corp., 347 King St., Northampton, Mass. Periscopes with camera attachments for observation of nuclear processes; binocular and monocular underwater periscopes, panoramic cameras for corrosion inspection of plate-type fuel elements; borescopes; precision optical and mechanical components. (246, 248)

Ladish Co., Cudahy, Wisc. Unusual fittings, valves, drop forgings and rolled ring components for reactors and the nuclear industry. (138, 140)

Leeds & Northrup Co., 4970 Stenton Ave., Philadelphia 44, Pa. Instrumentation for nuclear power plants. (209, 211)

P. M. Lennard Co., Inc., 1 Hanson Pl., Brooklyn, N. Y. Dry boxes, safety and control equipment of stainless steel and transparent plastic. (111)

Linde Co., 30 E. 42nd St., N. Y. 17, N. Y. Nuclear graphite, carbon and rare gases. (332, 336, 338, 340)

Lindsay Chemical Co., 258 Ann St., West Chicago, Ill. Thorium and rare earth for fuel element and other neutron absorption applications. (120)

Lukens Steel Co., Coatesville, Pa. Back-lighted panels showing application photographs of products and samples. (327)

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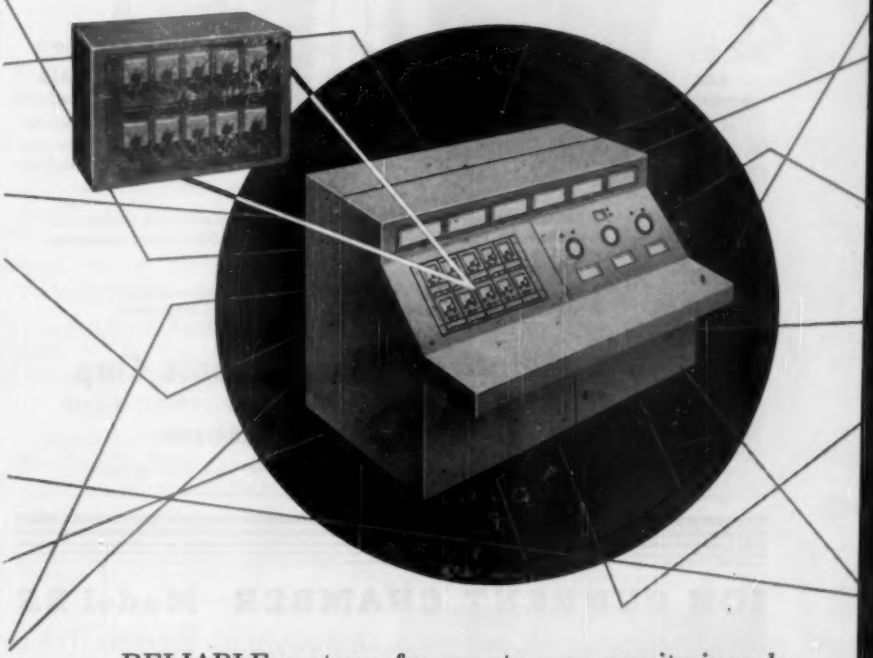

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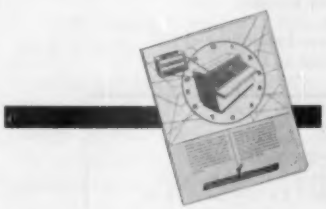

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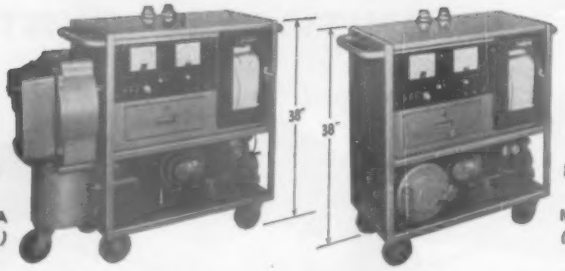

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NUCLEAR CONGRESS

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Mallinckrodt Chemical Works., 2nd & Mallinckrodt Sts., St. Louis, Mo. (300)

Mallory-Sharon Metals Corp., 980 Warren Ave., Niles, Ohio. Titanium, zirconium, and hafnium mill products. (119, 121)

Marchant Calculators, Inc., 1475 Powell St., Oakland 8, Calif. Calculating and adding machines. (214)

The Martin Co., Baltimore 3, Md. Fuel elements and components (354)

George T. Meillon, Inc., 132 Nassau St., N. Y. 38, N. Y. Dosimeters of various types, film badges and monitometers. (250)

Metals & Controls Corp., 34 Forest St., Attleboro, Mass. Fuel elements and component parts. (128)

Minneapolis-Honeywell Regulator Co., Wayne & Windrim Aves., Philadelphia 44, Pa. Nuclear reactor simulator, data handling system and multichannel oscillograph. (306, 310)

MSA Research Corp., Callery, Pa. Electromagnetic pumps, high-pressure temperature gauges, magnetic flowmeters, heat-transfer systems, chemical oxygen sources and NaK. (335, 337)

National Carbon Co., 30 E. 42nd St., N. Y. 17, N. Y. Nuclear-grade graphite, carbon and rare gases. (332, 336, 338, 340)

National Lead Co., 111 Broadway, N. Y. 6, N. Y. Lead and barites shielding and fuel elements. (431)

Neutronics Laboratory, 168th & Kilpatrick Ave., Tinley Park, Ill. Reactor control instruments. (112)

Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill. A subcritical student training reactor together with a complete laboratory of detection and measuring instruments. (341, 343)

Nuclear Development Corp. of America, 5 New St., White Plains, N. Y. Critical assembly and hot lab facilities. (345, 347)

Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind. Radiation detection instruments. (122)

NUCLEONICS, McGraw-Hill Publishing Co., 330 W. 42nd St., N. Y. 36, N. Y. Headquarters for meeting the editorial

and sales staffs of NUCLEONICS. (110)

Penberthy Instrument Co., 4301 Sixth Ave., So., Seattle 8, Wash. Lead glass radiation shield windows. (428)

Pergamon Press, Inc., 122 E. 55th St., N. Y. 22, N. Y. Technical and scientific books and periodicals. (124)

Plan Hold Corp., 5204 Chakemco St., South Gate, Calif. Vertical filing equipment for blue prints, maps, plans and other large sheets. (216)

Purolator Products, Inc., 970 New Brunswick Ave., Rahway, N. J. Industrial filtration equipment, chemical process equipment, air and gas filters, gas diffusers and separators. (136)

Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill. Nuclear data processing instrumentation. (331)

Radiation Instrument Development Laboratory, 5737 S. Halsted St., Chicago, Ill. Multichannel analyzers, scalers, pulse generators, counters, and various types of nuclear instrumentation. (445)

Saginaw Steering Gear Div., General Motors Corp., 3900 Holland, Saginaw, Mich. Ball bearing screws and splines. (322)

Sandusky Foundry & Machine Co., W. Market St., Sandusky, Ohio. Centrifugally cast cylinders and piping of stainless, plain carbon, and low alloy steels. (453)

Superior Steel Division, Copperweld Steel Co., Carnegie, Pa. Mill shapes produced in boron stainless steel, zirconium and its alloys and facilities for producing nuclear materials. (317)

Superior Tube Co., Box 191, Norristown, Pa. Small diameter metal tubing for nuclear energy applications, control rods and channels for nuclear reactors fabricated from plate, strip, bar and tubing. (312)

Sylvania-Corning Nuclear Corp., Bayside, N. Y. Nuclear fuel elements. (106)

Technical Associates, 140 W. Providencia Ave., Burbank, Calif. Health physics instrumentation, reactor control instruments, monitors and lead shields. (142)

Thermal Refractories Corp., 4501 Dell Ave., North Bergen, N. J. Beryllia, alumina, thoria, spinel, and zirconia of high purity and high-fired precision ceramics. (318)

Thomson Products, Inc., 2209 Ashland Rd., Cleveland 3, Ohio. Nuclear reactor components. (357, 360)

Tracerlab, Inc., 2030 Wright Ave., Richmond, Calif. Airborne-particulate monitor, gas monitor, water monitor for reactor effluents and associated electronic equipment. (422)

Union Carbide Corp., 30 E. 42nd St., N. Y. 17, N. Y. Nuclear graphite and carbon, rare gases and "The Union Carbide Nuclear Company Story." (332, 336, 338, 340)

United Shoe Machinery Corp., Balch St., Beverly, Mass. PWR refueling system, valve actuator and annualar speed reducer using the "Harmonic Drive" principle. (239, 241)

United States Radium Corp., Morristown, N. J. Radiation sources and radioisotope-excited light sources. (339)

United States Steel Corp., 525 William Penn Pl., Pittsburgh 30, Pa. Steel alloys, including stainless steel, in tubing and forgings. (240, 242, 244)

D. Van Nostrand Co., Inc., 48 Nassau St., Princeton, N. Y. Books. (413)

Vard, Inc., 2981 E. Colorado St., Pasadena, Calif. Control rod drive mechanisms. (416)

Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio. Instruments for radiation measuring, counting and monitoring. (408)

Vitro Corp. of America, 261 Madison Ave., N. Y. 16, N. Y. Nuclear activities, including mining, milling, processing, research and development and engineering. (144, 146)

Wah Chang Corp., 233 Broadway, N. Y. 7, N. Y. Rare metals. (314, 316)

Westinghouse Electric Corp., 3 Gateway Ct., P. O. Box 2278, Pittsburgh 30, Pa. Reactor models, pumps, valves, controls, fuels, electronic tubes, electric heating elements and air-particle detector equipment. (132, 231, 235, 237)

Wolverine Tube Div., Calumet & Hecla, Inc., 17200 Southfield Rd., Allen Park, Mich. Copper, copper-base alloys and aluminum tubing and trufin, the integral finned tubing. (206)

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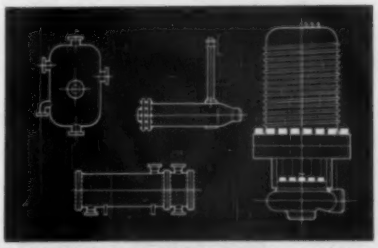

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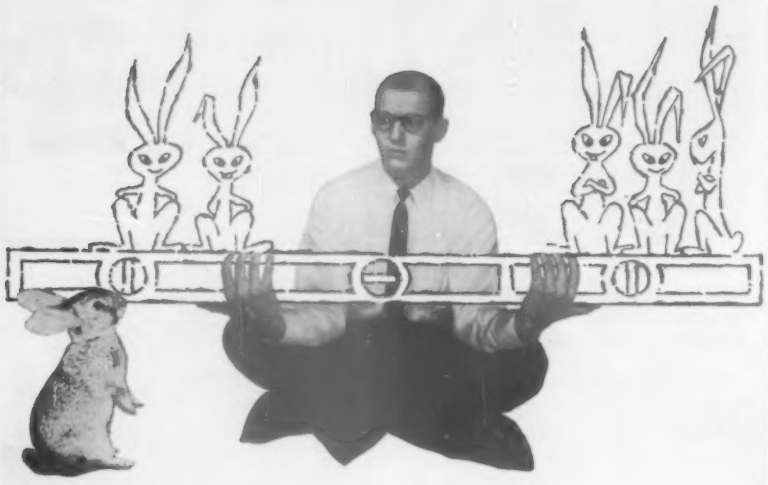

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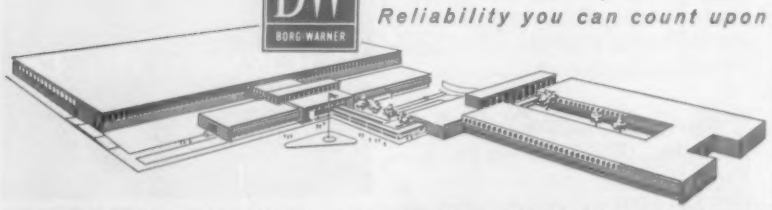

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Atomic Industrial Forum, 3 E. 54th St., N. Y. 22, N. Y. (147, 149)

Budd Co., 2450 Hunting[illegible]t Ave., Philadelphia 32, Pa. Auxil[illegible] detection equipment, custom r[illegible]ation facilities and design and engineering services. (419, 421)

Crawford Fitting Co., 884 E. 140th St., Cleveland 10, Ohio. Tube fittings. (243, 245)

Curtiss-Wright Corp., 631 Central Ave., Carlstadt, N. J. Reactors, extruded tubing and controls. (139, 141)

Engelhard Industries Inc., 850 Passaic Ave., East Newark, N. J. Gas purifying equipment, fuel element components. (213, 215)

General Atomic Div., General Dynamic Corp., P. O. Box 608, San Diego 12, Calif. Research reactor designs and uranium-zirconium hydride fuel element developments. (340, 342, 439, 441)

LETTERS

The West Is Still Golden

DEAR SIR:

I note on p. 22 of the Nov. '57 issue of NUCLEONICS under "Bad News" your statement that "General Electric let 100 of its Vallecitos Staff go late in the summer . . ."

The Vallecitos Laboratory staff is still being built up, and there has been no hitch in its planned expansion—at least so far. We have increased our staff from approximately 50 of a year ago to 170 to date and plan to continue to build it up slowly and carefully. Because of the glamour of atomic power and the attractiveness of living in California, we are finding that we can be very selective in our recruiting and feel that we have an experienced and extremely capable staff ready to carry on not only our own research and development load, but to assist others who are trying to get into this business.

—R. D. BENNETT, Manager
Vallecitos Atomic Laboratory
Pleasanton, California

maximum yield observed for zero B_z field was 3×10^6 neutrons. The dependence of the neutron yield on pressure and helium contamination showed (a) that the yield was proportional to the pressure increasing a facort of 2.3 between 70 and 200 microns and (b) the fraction f of the helium contamination lowered the yield according to the relation $(1 - f)^3$ (these results were obtained with a B_z field of 200 gauss). An observed energy shift of ~0.17 Mev in the axial neutron-energy distribution (gotten from nuclear plates situated behind the cathode and anode) corresponds to a 20-kev deuteron colliding with a deuteron at rest or to a group of interacting deuterons traveling toward the cathode with a velocity of 7×10^7 cm/sec. Plates were also exposed radially at three positions along the discharge—the results are compatible with a uniform neutron distribution from the cathode to within 5 cm of the anode beyond which the yie ldis lower. All the plate exposures were made with a 200-gauss B_z field and 50-kv bank voltage.

The dependence of neutron yield on applied magnetic field, helium contamination, gas pressure, and voltage, as well as the long neutron pulse duration suggests a neutron-production mechanism different from the usual instability process. However, it is clear, from the anisotropy in the neutron-energy spectrum at 200-gauss axial magnetic field, that directed motion of the reacting deuteron system exists. This anisotropy is smaller than that reported previously (*2, 3,*) for instability neutrons without axial magnetic field even though the applied electric field in Columbus II is appreciably larger.

Columbus S-4 (9)

A linear discharge device, Columbus S-4 was constructed to test the effect of increased tube diameter and interelectrode spacing on the properties of a B_z-stabilized pinched discharge.

Description. The apparatus utilizes a 75-μfd, 20-kv capacitor bank with external inductance of 0.075 μh. The discharge tube is a 5.0-in. i.d. porcelain (Mullite) cylinder with 24-in. spacing between electrodes. A close fitting cylindrical return conductor of 1/16-in. stainless steel provides negligible delay in the 2-msec rise of the longitudinal (B_z) field which is set up by an external solenoid and capacitor bank. Provision has been made for radial insertion of a magnetic probe halfway between the electrodes.

Magnetic probe measurements of the B_θ and B_z fields were made at condenser voltage of 1.5×10^4 volts; $B_z = 1750$ gauss; deuterium pressure, 40 μ Hg; i_{max}, 2.5×10^5 amp; time to first current peak, 6 μsec and for times extending through three half cycles of the bank current. Although the shot-to-shot reproducibility of the probe traces became imperfect after 3 μsec owing to an apparent small amplitude flutter of the plasma column, the spread in the trace amplitudes was still sufficiently small to allow the plotting of meaningful field distributions and the calculation of approximate plasma pressures.

A pressure-balance calculation using the B_z and B_θ amplitudes at 6 μsec after the starting of current, i.e., at the current maximum, showed the plasma pressure at the tube axis and at this time appears to be about 12 atm; if the plasma is assumed to be uncontaminated and pinched to the same radius as the longitudinal current, the temperature should be in excess of $3 \times 10^{6\circ}$ K.

Since a temperature this high, together with the assumed central density, should result in an easily detectable neutron yield, i.e., the order of 100/cm^3/μsec, a series of counter experiments was performed. A plastic scintillation counter was found to give pulses centered at the current maximum, and tests with paraffin interposed between the counter and discharge tube established the radiation to be neutrons. The yield was found to be too small to activate a silver foil counter to significantly greater than a background count, and it was concluded from the known counter calibration that the total yield was fewer than 10^5 per discharge. The numbers of counts observed in the plastic scintillators made it apparent that some of the discharges yielded more than 10^3 neutrons. The number has not been accurately fixed at the present time.

Runs were made to measure relative neutron yield as a function of bank voltage, B_z, D_2 pressure, and contaminant fraction in the gas. The yield over the half cycle was obtained by integrating the photomultiplier anode current for this time. Ten shots were taken at each condition of the system.

Most of the data were taken at conditions more favorable for neutron production than those used for the magnetic field measurements. However, counts were observed in significant numbers at 15-kv bank voltage and 1,750 gauss B_z; typically, one observed the order of 10 counts per discharge in a 5- × 5-in. cylindrical plastic scintillator placed 8 in. from the center of the tube. At this condition, the neutrons are produced in a time interval 4 μsec wide, centered near the current maximum.

Although the pinch configuration for the case of the measured field distribution (15-kv bank voltage, 1750 gauss B_z) is clearly stable against breakup by kinking and the 16-kv 1500 gauss condition also appeared stable in this sense from initial probe surveys, it is not established that the runs which involve higher ratios of bank voltage to B_z are stable. One must, therefore, allow the possibility that the neutron output in the lowest B_z and highest bank voltage cases results from some acceleration mechanism associated with instability. Even in the configuration whose B_θ traces are shown, the fluttering of the fields near maximum current may represent strong local field inhomogeneities which could provide a particle accelerating mechanism. It is clear, however, that the variations of yield with V and B_z are consistent with a thermonuclear origin of the neutrons since the plasma compression and current density are sensitive to variation of these parameters.

Work is progressing on the problem of determining pinch stability for the conditions where it is now uncertain. An effort will also be made to measure the degree of energy isotropy of the neutrons, since anisotropic energy distribution has in the past identified the neutron yield from several devices as being nonthermonuclear.

Perhapsatron S-3 (10)

Hydromagnetic calculations on idealized models of the pinch have indicated that stability might be attained by a combination of a central axial magnetic field and conducting walls, provided that certain restrictions on compression and $8\pi p/B^2$ (p = the plasma pressure) are obeyed. The problem is actually more complicated than these simple models suggest, especially when the finite thickness of the boundary layer between external magnetic confining field B_θ and internal magnetic stabilizing field B_z is taken into account.

Experiments at Los Alamos on straight tubes using magnetic probes have measured substantial plasma pressure confinement with appreciable stability by using axial magnetic fields. It proved unexpectedly difficult to do as well in toroidal geometry because of the technical difficulty of inducing high-voltage gradients and also because of the presence of unavoidable gradients in electric and magnetic fields across the discharge tube cross section. After a progression of machines extending over several years, Perhapsatron S-3 began to show (mid-1957), by magnetic probe measurements, more symmetrical detachment of the current channel from the walls. This apparatus is shown on p. 90.

Magnetic probe measurement of plasma pressure, nkT, made in Perhapsatron S-3 at two stages in the current wave $t = 4$ μsec, 2.0×10^4 amp and $t = 6$ μsec, 2.3×10^5 amp shows penetration of the B_θ magnetic field toward the pinch axis with some increased confining current density along the axis and little current outside the pinch. The nkT is evaluated by substitution in the pressure balance equation,

$$\left(nkT + \frac{B^2}{8\pi}\right)_{r_1}^{r_2} = -\frac{1}{4\pi}\int_{r_1}^{r_2} \left(\frac{B_\theta^2}{r} + \frac{B_z^2}{R}\right) dr + C$$

where $B^2 = B_\theta^2$, r and R are the radius of curvature of B_θ and B_z, respectively, and C is a constant evaluated at some position at which nkT is known. The calculations of nkT are not precise since (1) the radii of curvature of the magnetic field lines are assumed from symmetry and (2) uncertainties of the position of the discharge axis seriously affect the integration in its vicinity. The pressures are consistent with appreciable average temperatures, $>1 \times 10^{6\circ}$ K. Also the cooling effect of impurity influx from the walls is suggested by the lower pressures at 6 μsec, compared with those indicated at 4 μsec. This is paralleled by the rise in impurity spectral line intensities emitted from the discharge, up to this time quite faint. It was also observed that the small magnetic probe, diameter 1.7 mm, when extended into the discharge caused the impurity lines to appear earlier. This suggests that the temperature would be higher and the current sheath thinner when the probe was absent.

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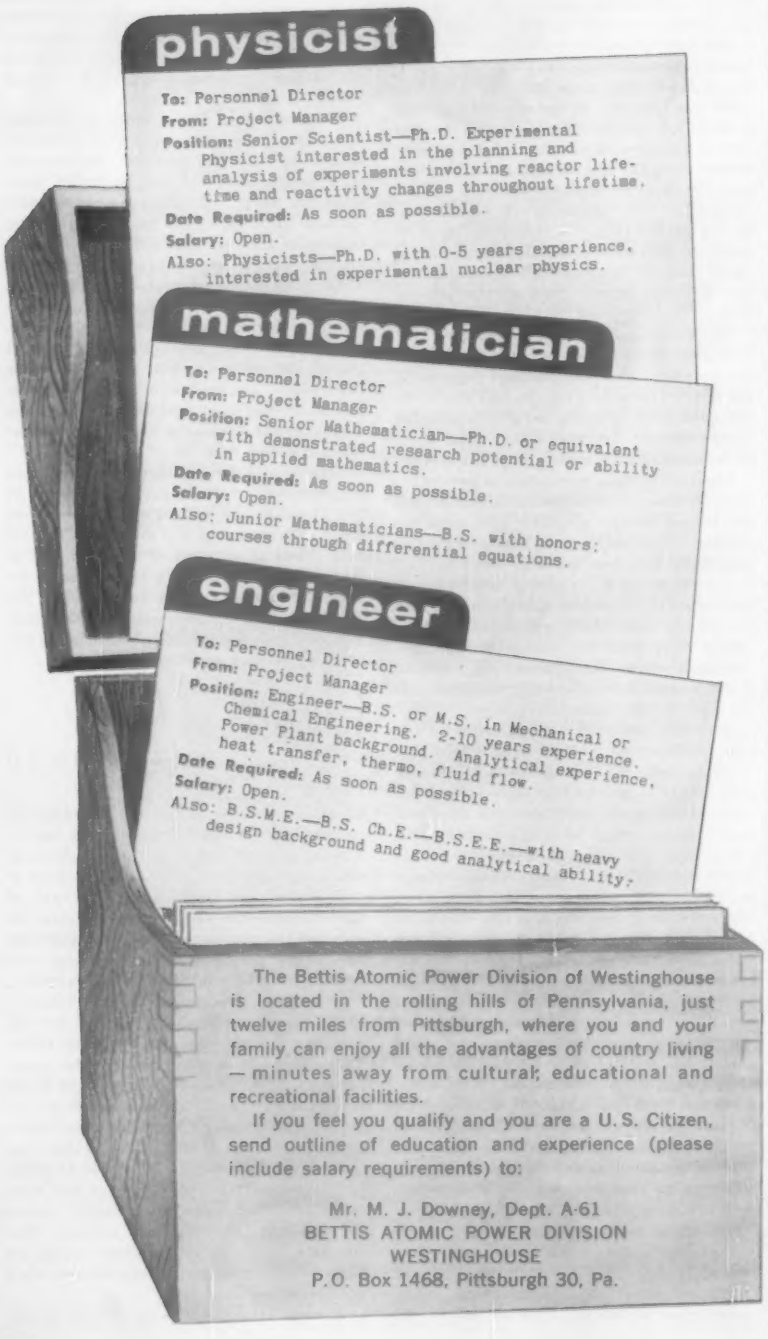
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ter, 50 cm high) showed neutron emission (December 17, 1957) of 10^4 per discharge. Substitution of a quartz (Vycor) torus for the one of pyrex glass raised the average output to 2×10^4 neutrons per discharge. Addition of a laminated iron core improved the coupling in the early stages of the current cycle before it saturated and gave a further small increase. Neutron yields up to 10^6 per discharge have been observed.

Neutron intensity versus time as detected by a proton recoil scintillation counter shows a burst of duration of approximately 2 μsec starting at approximately 3.0 μsec, after gas breakdown with successive smaller bursts superimposed on a tail of duration 10 to 15 μsec. It also seems definite that some neutron emission continues on through the discharge current zero and occasionally up to and beyond the second current maximum (approximately 30 μsec). A pulse of neutrons is at times associated with the second current zero, approximately 60 μsec. This may have interesting implications. There is a well-defined optimum B_z, with no yield at zero B_z field. The yield rises with diminishing deuterium pressure and the lower limit in this direction is determined by failure to obtain gas breakdown, (even with use of r-f preexcitation). The yield is sensitive to contaminants and to the quality of the base vacuum pressure. Five per cent nitrogen reduces the yield by a factor of two. Yields are variable at fixed operating conditions by a factor of about three.

X rays appear in a sharp burst, duration of approximately 1 μsec, approximately 0.9 μsec after gas breakdown which is before the time of neutron emission. Little or no x-ray yield is observed under the conditions of maximum neutron yield. The x-ray intensity increases with deuterium pressure; whereas the neutron intensity increases with decreasing pressure. At high pressures, 400 μ, x-ray energies as high as 0.9 Mev have been measured with 12-kv primary voltage and 5000 gauss B_z.

A spectrogram taken during three complete discharges at 11 A/mm dispersion over the range 3000 to 6600 A shows a strong continuum throughout, with a few lines greatly broadened approximately 30 A tentatively identified as Si II, Si III.

Experimental limitations. One of the central features of the design of Perhapsatron S-3 is the thinness (0.3 cm) of the glass walls of the torus and its close fit to the metal primary, based on the unequivocal predictions by theory of the bad effect of B_z external to the pinch on stability. This has made the glass torus very fragile and easily broken by strains transmitted to it from the heavy primary under electromagnetic forces. The neutron yield rises between 14- and 15-kv primary voltage with higher voltages limited by glass torus failure. A precision alumina porcelain torus when delivered is expected to reduce these difficulties with the possible added advantage that alumina is known from other experiments to be superior to quartz in the contaminants it supplies to the discharge.

Results. A temperature of 600 ev (compression 9) would be consistent with the observed yield of neutrons, and the pressure

This article starts on page 90

balance equations would support this. Magnetic probes indicate that the pinch undulates as a whole with an amplitude of about 2 mm. The diminution in neutron yield after the initial burst is a matter for concern and finds an explanation in terms of cooling by the influx of impurities (approximately 3.6 μsec). The observed sensitivity to impurities is supporting evidence for a thermonuclear reaction but has been misleading in the past, witness the great sensitivity of instability neutrons to impurities (*16*).

It is fairly safe to say, that at any rate the fringe of thermonuclear temperatures approximately 500 ev is being approached. The principal anxiety arises from the fact that it is precisely at this point that conditions are ideal for simulation of a thermonuclear reaction by a Fermi mechanism (*17*). Reflection of deuterons from magnetic disturbances traveling at the Alvén speed, $\sqrt{B^2/4\pi\rho}$, gives deuterons in the 12-kev energy range after very few reflections, yet a small fraction of the gas, 0.6 per cent with this energy, equals the thermonuclear yield of a plasma at 600 ev. Nor is it easy to distinguish the two experimentally. Refined nuclear emulsion techniques could do it but would require several thousand discharges to accumulate enough intensity at the present output level of Perhapsatron S-3. Comparison of yields with DD and DT gas fillings can also be used, but it requires more reproducibility than prevails at present.

ZETA (12)

ZETA is located at the Atomic Energy Research Establishment, Harwell; a major part of the engineering design and construction was done by the Metropolitan-Vickers Electrical Co. Ltd. Basically ZETA is a ring-shaped discharge tube of 1-in.-thick aluminum, 1-meter bore and 3 meters mean diameter. The contained gas, usually at a pressure of about 10^{-4} mm of Hg is made weakly conducting by a radio-frequency discharge. The toroidal-shaped ionized gas plasma forms the secondary of a large iron-cored pulse transformer (see p. 91). By discharging a condenser bank, storing up to a maximum of 5×10^6 joules, into the primary of the transformer, a unidirectional current pulse up to a maximum of 200,000 amp is produced. The current in the ionized gas lasts from 3 to 4 msec, and the pulse is repeated every 10 sec. A steady axial magnetic field variable from 0 to 400 gauss is generated by current-carrying coils wound on the torus. Pinch-effect instabilities have been suppressed in ZETA by the combination of this axial magnetic field parallel to the flow of the discharge current and by the fields produced by eddy current induced in the surrounding thick metal walls when the current channel changes its position.

The energy of the particles of an ionized gas can be increased by adiabatic compression, by shock waves within which irreversible heating takes place and by joule heating. All these processes contribute to raising the gas temperature in ZETA, but joule heating is the most important.

Electrical characteristics. A typical current and voltage characteristic is shown in Fig. 1. The top trace is the "voltage per

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turn" measured by a loop around the central limb of the transformer core. The length of the discharge path is approximately 1000 cm so that the initial electric field at the boundary of the ionized gas is about 1 volt/cm. The primary winding is short circuited when the voltage per turn is zero, thus preventing the charge on the condensers from reversing. The third trace shows the current flowing in the gas, which persists for about 2 msec after the transformer primary is short circuited. As the current decreases, the plasma expands until it reaches the walls; it is cooled and impurities are thrown into the gas from the walls. The sudden increase in resistance, which accompanies the cooling, causes an increase in dI/dt and the appearance of the severe voltage transient towards the end of the top trace in Fig. 1. Destructive voltage transients of this type can be suppressed by the addition of 5% nitrogen or neon without affecting the neutron yield.

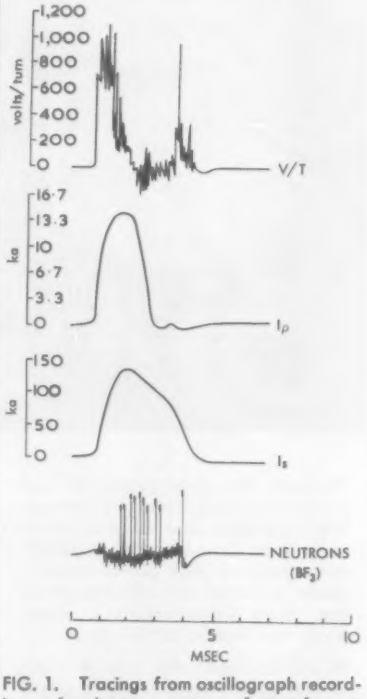

FIG. 1. Tracings from oscillograph recordings of voltage per turn of transformer, primary current I_P, and secondary current I_S. Lower trace shows pulses produced by individual neutron capture in BF_3 counters

Stability. Probe measurements, and streak photographs of the current channel taken through a slit in the vacuum vessel, show the current channel to be quasistable and clear of the walls for the greater part of the current pulse. The center of the current channel is displaced towards the outer wall because of the tendency of the ring current to expand. This expansion is opposed by eddy currents in the metal walls of the forms.

Measurements of the internal magnetic fields in the plasma are reproducible and show that the initial axial lines of force are trapped in the gas and drawn towards the axis as the plasma column contracts. In general, the resultant lines of magnetic force are helical and vary in pitch over the cross section of the plasma. The observed stability has not been explained satisfactorily from theoretical consideration.

Neutrons. Neutron emission arising from the D-D reaction is observed for gas currents in deuterium in excess of 84 kiloamps. Emission occurs for a period of about 1 msec, centered about the peak current. Neutron emission was uniform, within a factor at two, around the torus.

TABLE 1—Neutrons from ZETA*

Current I_s (kiloamps)	*Total neutron yield per pulse*	*T_e (10^6°K)*
84	0.4×10^4	2.4
117	8.1	2.9
126	9.2	3.3
135	14.2	3.6
141	26.5	3.8
150	41.6	4.0
177	108	4.5
178	125	4.6
187	134	4.65

* Conditions: gas $D_2 + 5\%$ N_2; pressure $\frac{1}{8} \times 10^{-3}$ mm, $B_z = 160$ gauss.

Table 1 shows the average number of neutrons emitted per pulse as the peak current is increased. The third column gives the temperatures required to produce the observed neutron yields assuming a thermonuclear process. In calculating these figures it has been assumed that the current channel is 20 cm in diameter, emits neutrons uniformly for a period of 1 msec, and all the deuterium initially present is contained in the current channel. Since the reaction rate is an extremely sensitive function of temperature, variations in these parameters do not greatly affect the calculated temperature T_e.

Within the pressure range investigated ($0.8–10 \times 10^{-4}$ mm), the neutron yield decreased with increasing pressure. Neutrons were observed when 25% of the gas initially present was nitrogen, but the yield was much reduced.

No correlation is observed between the time of neutron emission and the voltage fluctuations during the current pulse. However, neutrons are produced by the large voltage transient at the end of the pulse, but these can be eliminated by the addition of nitrogen gas.

X-rays are observed towards the beginning of the current pulse. Their average energy is 20–30 kv and on the average some 10^6 quanta/pulse are emitted by the whole tube. These X-rays are produced by electrons that have gained energy continuously by many revolutions around the torus. In no circumstances have X-rays been observed which will penetrate ¼ in. of lead. The number and energy of the X-ray quanta are insensitive to gas and current but increase in intensity as the axial magnetic field is increased.

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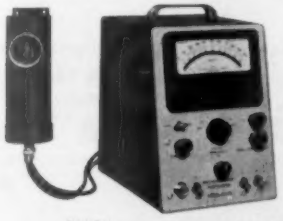

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Conclusions. The preliminary results reported here demonstrate that it is possible to maintain hydrogen gas in a state of virtually complete ionization with a particle density lying between 10^{13} and 10^{14}/cm³. The mean energy of the ions and electrons in the plasma is certainly of the order of 300 ev. The containment time and the high electrical conductivity are both adequate for the detailed study of magnetohydrodynamical processes. In order to identify a thermonuclear process, it is necessary to show that random collisions in the gas between deuterium ions are responsible for the nuclear reactions. In principle this can be done by calculating the velocity distribution of the reacting deuterium ions from an exact determination of both the energy and direction of emission of the neutrons. The neutron flux available at present is insufficient to attain the desired accuracy of measurement.

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Neutrons have been produced with this device and temperatures up to 3.8×10^6 °K indicated. However the neutron intensity is insufficient to determine by plate techniques whether or not they are thermonuclear.

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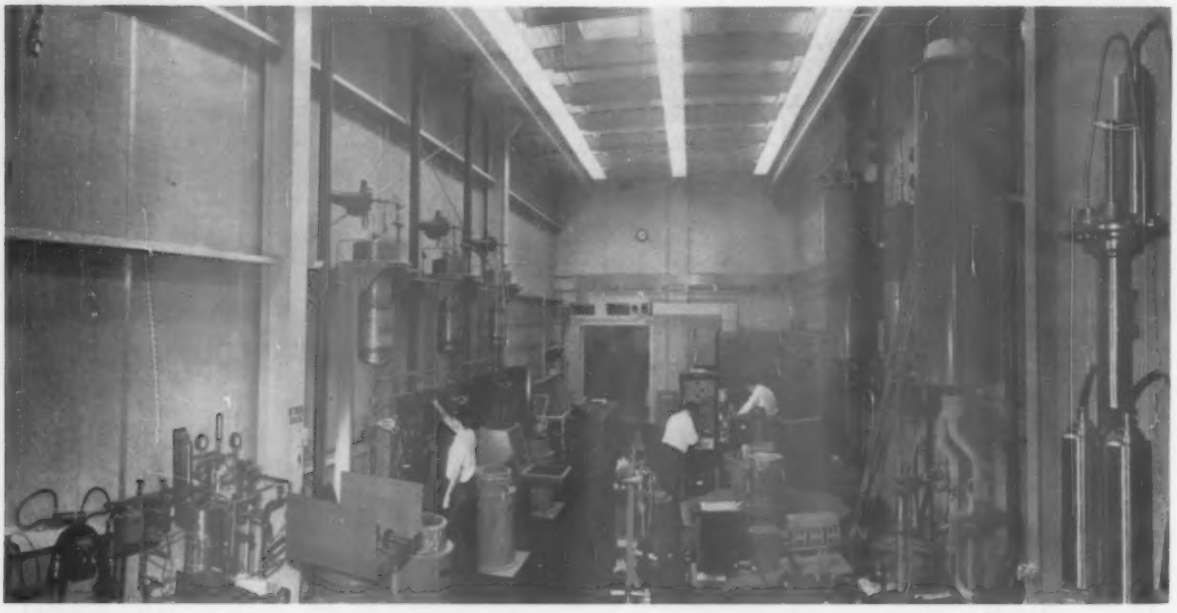

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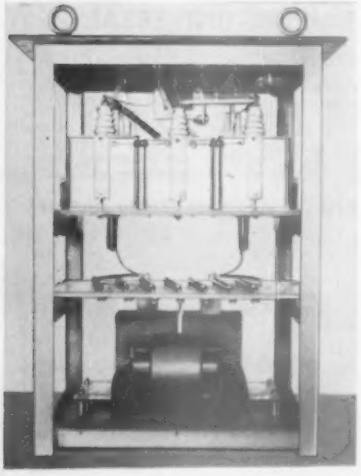

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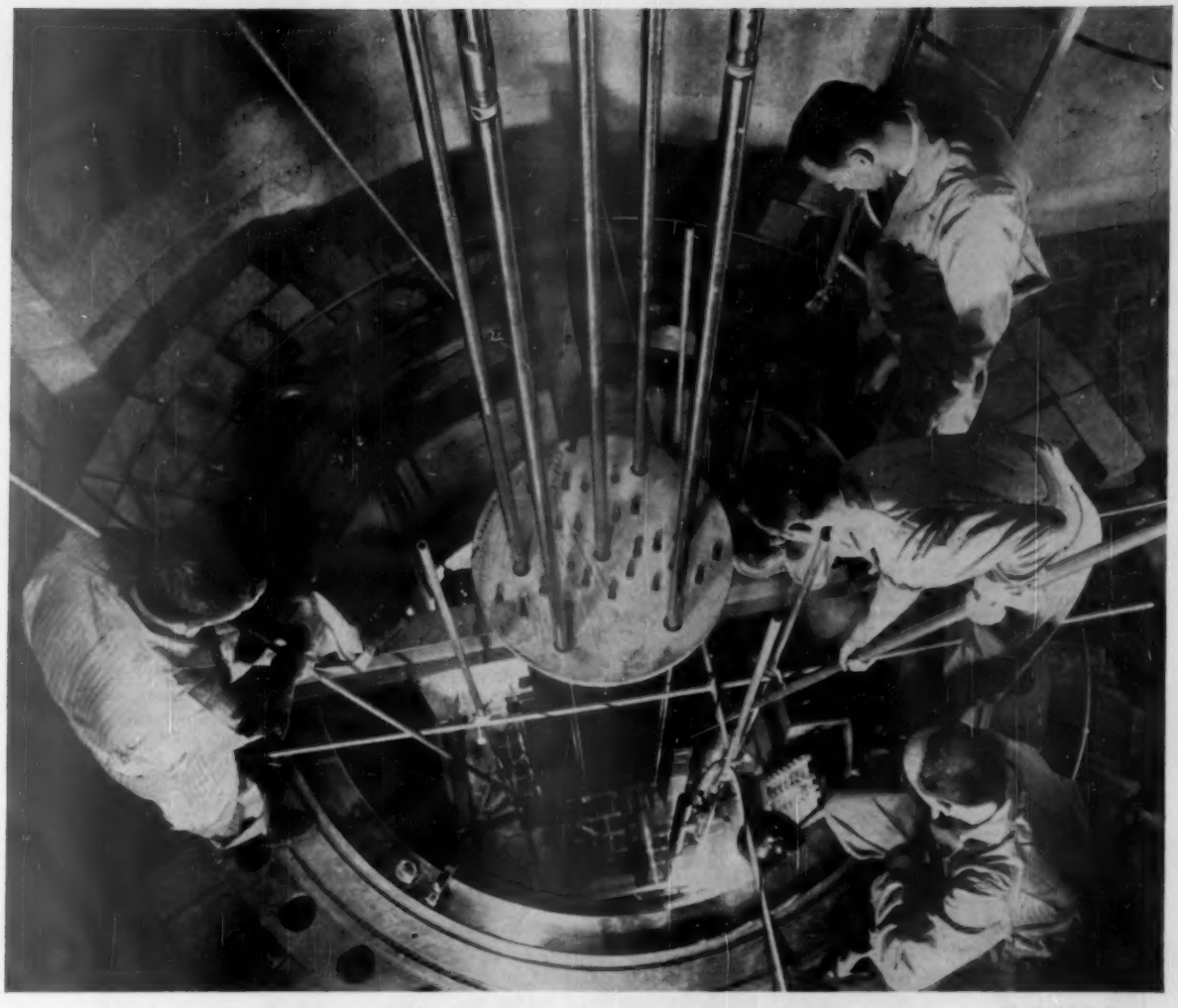

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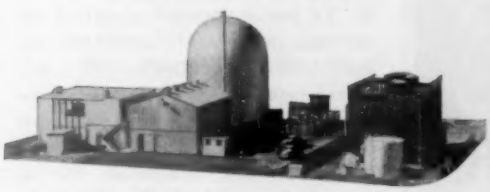

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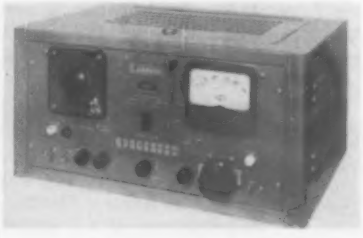
vials of radiopharmaceuticals such as iodine-131, sodium-24, gold-198, iron-59 and cobalt-60, or radium needles or capsules.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Voltage and Current Calibrator

Model 6020B (above) is a voltage and current calibrator designed for the measurement of pulse amplitudes. Although primarily for use in magnetic core testing and grading, the unit is also applicable to general pulse, d-c, and sine-wave measurement. Two variable calibrated reference voltages (0.001% stability) and the signal to be measured are sampled and attached to an oscilloscope for a superimposed display. The two references can be set for tolerance checking or for 0.5% amplitude measurement by adjusting to the same level as the signal. Ten ranges cover 0–500v (100 mv full scale on lowest range) and 0–1000 ma. Effective zero suppression is provided on the output to allow use of a high-gain oscilloscope for accurate comparison.—Electro-Pulse, Inc., 11861 Teale St., Culver City, Calif.



Proportional Counter

Model PC-1A (above) is a proportional counting system for alphas in the presence of betas, and the total of alpha and beta-gamma. The instrument features low power requirements, industrial type transistors and printed circuitry, binary scaling unit, automatic gas purge system with variable purge time, preset timer and gas-flow proportional counting chamber.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Pitot Tube

Model CMR-7362 is a pitot tube made of stainless steel, bronze, brass or monel. Differential pressure between upstream and downstream side of the tube is ~25–50% greater than with other pitot tubes. A safety lock is provided so that the impact opening always faces upstream.—Harris D. McKinney, Inc., 12 South 12th St., Philadelphia 7, Pa.

INDUSTRY NOTES

Du Pont has entered into a joint development agreement with **Thompson Products** in a move to step up progress of high-purity niobium and high-strength, high-temperature niobium alloys.

Atomic Energy Waste Disposal Service, Oakland, Calif., has announced that, in addition to their nationwide radioactive waste collection and disposal service, they have added another: radioactive waste container rental service.

Atomic Accessories Inc., Belrose, N. Y., has been formed to distribute a complete line of accessories for laboratories engaged in work with radioisotopes.

Baldwin-Lima-Hamilton has named William A. Kerr, formerly vice president and general manager of **Tracerlab's** nuclear divisions, as general sales manager of its Electronics & Instrumentation Div.

Mid-Century Instrument, New York, N. Y., has announced plans for the opening of a $250,000 Manhattan Computer Center in February, 1958.

Correction. Item headed Canned-Motor Pump (NU, Nov. '57, 202) gave Flexonics Corp., Maywood, Ill., as manufacturer. Actually, Flexonics supplies only the stator liner to certain canned-motor-pump manufacturers. These liners are fabricated from Inconel sheet formed and welded into long, thin-walled tubes that meet the most rigid requirements as to soundness, uniformity of cross section, 100% penetration of the continuous-seam weld and uniformity of finish.

NEWSMAKERS

Raymond D. Maxson, senior vice-president of Commonwealth Edison Co. in charge of the Dresden nuclear power station project, is moving to Sargent & Lundy, Chicago engineering firm, as consulting engineer concentrating in atomic power. However he will continue to serve his former firm as senior consulting engineer.

Detroit Edison named the men who will head the operating teams of the Enrico Fermi fast breeder power plant at Lagoona Beach, Mich., near Detroit. Power Reactor Development Co.'s. **Frank W. Shutko,** 44, will be superintendent of the reactor section of the plant. An electrical engineer and an ORSORT graduate, he joined the Fermi project in 1956 and is now in training at AEC's Materials Testing Reactor in Idaho. He will return in midsummer to Lagoona Beach to assist in assembly and testing of the Fermi reactor components. Detroit Edison's **Clarence H. Clark,** 50, superintendent of the Marysville power plant, will be superintendent of the steam turbine-generator station, which will be owned by Edison and powered by steam from the reactor, owned by PRDC, a 21-company syndicate. Clark, with Detroit Edison since 1930, will be trained at AEC's Pressurized Water Reactor, Shippingport, Pa., or its Sodium Reactor Experiment at Santa Susana, Calif., or both. Meanwhile Atomic Power Development Associates, the research and design syndicate for the Fermi reactor, named **Wayne H. Jens** assistant technical director; he had been project engineer at Nuclear Development Corp. of America.

Shutko

Clark

Jerome Ottmar, heretofore general manager of the Nuclear Products division of Metals & Controls Corp., becomes president of M&C Nuclear, Inc., the new wholly-owned subsidiary corporation set up Jan. 1 by Metals & Controls. He heads an organization that now employs 600. **George L. Williams,** treasurer of the parent firm, will also be treasurer and clerk of the new subsidiary. **James J. Dutton,** formerly with Bell Nucleonics, has joined M&C Nuclear.

Richard H. Graham, head of nuclear engineering and development at Lockheed Missile Systems, has been appointed technical secretary to the Advisory Committee on Reactor Safeguards by AEC. He had been chief of reactor engineering in AEC's Reactor Development division, 1954–1956.

Karl M. Mayer has been named to the new position of director of economic research at Nuclear Products-Erco division of ACF Industries Inc. With AEC from 1948 to 1955, he was industrial economics consultant to Stanford Research Institute from 1955 through 1957, specializing in nuclear energy.

Boris Lochak has been named chief engineer and elected a vice president of Gibbs & Hill, Inc., consulting engineers. He will direct all design and construction engineering services in the power field, among others.

Westinghouse has rearranged its top executive management, with **Mark W. Cresap, Jr.,** executive vice president and a director, moving up to become president and chief administrative and operating officer. **Gwilym A. Price,** formerly chairman and president, becomes chairman of the board. He is also head of a new triumvirate, a policy and finance committee, composed of himself, Cresap, and **E. V. Huggins,** formerly vice president-corporate affairs and now chairman of the executive committee. The three-man committee will have primary responsibility for determination of policies to be followed in planning and conducting company business.

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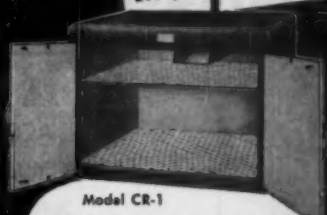

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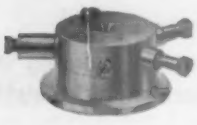

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Charles E. Oakes, president of Pennsylvania Power & Light Co., has been elected board chairman, and **Jack K. Busby,** executive vice president of the firm, succeeds as president. Oakes continues as chief executive officer.

J. W. McAfee, president of Union Electric Co. of St. Louis, was elected president of the Edison Electric Institute, succeeding **Donald S. Kennedy** of Oklahoma Gas & Electric. **J. E. Corette,** president of Montana Power Co. is the new EEI vice president.

George Manov, technical assistant to Atomic Energy Commissioner **Willard F. Libby,** is

joining Tracerlab as technical director of its reactor monitoring center in Richmond, Calif. A pioneer in development of isotope applications, he spent 12 years working on radioactivity at the National Bureau of Standards before joining AEC at Oak Ridge in 1948. He was in charge of the U. S. exhibit swimming pool reactor at the Geneva Conference in 1955.

Pierre Hazebroucq is the new commercial manager of the Compagnie d'Applications et de Recherches Atomiques (CARA) in Paris, a nuclear products firm set up by eight French manufacturing firms (NU, Feb. '57, R11).

H. K. Ferguson Co., engineers and builders, has named **Ralph W. Olmstead** executive vice-president; **James R. Fraser** vice-president, engineering; and **William E. Hark** vice-president, construction.

James D. Moore, chief process engineer, has been promoted to production manager of Vitro Uranium Co., and will be responsible for all plant operation, engineering and maintenance, and process research and development. He joined Vitro in 1951.

Nuclear physicist **Samuel Penner** has joined the betatron section of the atomic and radiation physics division at the National Bureau of Standards.

Philip Thompson, business manager of Nuclear Metals, Inc., has been appointed to the Massachusetts Commission on Atomic Energy by Governor Furcolo.

Gilbert Associates, Inc., has selected **James R. Stoudt** to be manager of its nuclear energy division at Reading, Pa. He had been in charge of engineering and economic studies in the nuclear power field made by Gilbert for both utility clients and AEC.

Argonne National Laboratory has appointed **Walter S. Fagan** a chemical engineer in the Reactor Engineering division; **Paul E. Brown** an associate engineer in the same division; and **Ray O. Haroldsen** an electrical engineer in the Idaho division at the National Reactor Testing Station.

Allis-Chalmers has chosen **H. A. Bartling** to be assistant to the general manager of its Nuclear Power division, and has assigned **Donald J. Nolan** to the division. Bartling had handled special assignments for Allis-Chalmers in the Manhattan District project.

John P. O'Meara was named laboratory director of radiation physics for the Central Research and Engineering division of Continental Can Co., Chicago. One of his major responsibilities will be in the field of irradiated foods, which Continental Can will explore at the Plainsboro, N. J., facilities of Industrial Reactor Laboratories.

B. D. Thomas, director of Battelle Memorial Institute, has been named

to the presidency of BMI, succeeding **Clyde Williams,** retiring. A physical chemist and mineralogist, he joined Battelle as a research engineer in 1934, became assistant director in 1942, vice-president in 1955, and director a year ago.

AEC has detailed **John V. Vinciguerra,** assistant manager for administration at Savannah River Operations Office, to the Office of Special Projects in Washington for six months: there he will serve as project manager for U. S. participation in the Fifth International Electronic and Nuclear Exposition and Congress in Rome. **James J. Wise,** director of the budget and finance division at SROO, will serve in Vinciguerra's place during his absence.

George J. Rotariu, formerly director of nuclear engineering at Cook Electric Co., has joined Booz-Allen Applied Research, Inc., as director, nuclear technology.

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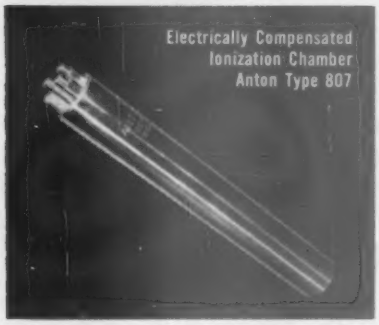

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NUCLEAR CALENDAR

March 3–6—American Society of Mechanical Engineers' gas turbine power division conference and exhibit, Washington, D. C. (*Shoreham*). Contact L. S. Dennegar, ASME, 29 West 39 St., New York 18.

March 17–21—Nuclear Congress will include four events, at International Amphitheater, Chicago: **A.** Fourth Nuclear Engineering & Science Congress (EJC), running all five days. Contact congress manager, American Institute of Chemical Engineers, 25 West 45 St., New York 18. **B.** Atomic Industrial Forum Atom Fair, all five days, contact J. V. Friel, 304 Architects Bldg, Philadelphia 4. **C.** Sixth Hot Laboratories & Equipment Conference, 19–20th; contact Frank Ring, Jr., ORNL, Oak Ridge, Tenn. **D.** Sixth Atomic Energy in Industry Conference, National Industrial Conference Board, 17–19th; contact John J. McMahon, 460 Park Ave., NYC.

March 24–27—National Convention IRE, New York (*Waldorf, Coliseum*). 275 papers in 55 sessions. Contact E. K. Gannett, IRE, 1 E. 79 St., N. Y.

March 26–28—20th meeting, American Power Conference, Chicago (*Sherman*). Contact R. A. Budenholzer, Illinois Institute of Technology, 3300 Federal St., Chicago 16.

March 27–29—American Physical Society, Chicago (*Univ. of Chicago Study of Metals Institute*). Solid state and high-polymer physics programs. Contact K. K. Darrow, Columbia U., N. Y.

March 31–April 2—Conference on utilization of atomic energy, Texas A. & M. College, College Station, Tex. Will cover reactors, isotopes, waste disposal, petroleum applications, education. Contact R. E. Wainerdi, Texas A. & M., College Station.

April 8–10—Brooklyn Polytechnic Institute international symposium on electronic waveguides, New York (*Engineering Societies Bldg., 33 W. 39 St.*). Includes papers on microwave properties of high- and low-density plasmas. Contact Jerome Fox, Brooklyn Polytech, Bklyn. 1, N. Y.

April 20–23—Canadian–U. S. chemical engineering conference, American Institute of Chemical Engineers and Chemical Institute of Canada, Montreal. Contact H. R. L. Streight, DuPont Co. of Canada, PO Box 660, Montreal, Quebec, Canada.

May 27–29—Third annual reactive metals conference, American Institute of Mining, Metallurgical and Petroleum Engineers, Buffalo (*Statler*). Contact S. F. Urban, National Lead Co., Buffalo, N.Y.

June 2–4—American Nuclear Society annual meeting, Los Angeles (*Statler*). Contact W. R. Hainsworth, Fluor Corp., Los Angeles.

NUCLEAR CAMPUS

• The University of California's first training reactor has gone into operation in Cory Hall on the Berkeley campus. Acquisition of the 0.1-watt AGN-201 unit was made possible by a $142,000 grant from AEC. In addition to its use for student instruction and demonstration, the reactor will also be used at somewhat higher power for reactor materials studies.

• Canadair Ltd. subsidiary of General Dynamics is building a $439,000 subcritical reactor for the Univ. of Toronto. It is Canada's first subcritical reactor for education, and will be completed this month. Eldorado Mining & Refining will lend the university three tons—$100,000 worth—of uranium.

• A university nuclear training "package laboratory," including not only a small subcritical reactor but also aid in getting AEC funds to pay for it, is being offered by Nuclear-Chicago Corp. The Model 9000 water-moderated, natural uranium subcritical reactor consists of a 6-ft high, 4-ft dia stainless steel tank containing 435 gal tap water and a lattice of 275 watertight aluminum tubes containing 1" × 8" natural-U slugs. A polonium or plutonium-beryllium neutron source can be moved about in the center. The assembly weighs 5 tons.

Other components of the package lab are student radioactivity detection and counting systems; gamma-ray scintillation spectrometer assemblies; systems for measuring neutron flux in the subcritical reactor; an automatic strip foil analyzer for determining exponential neutron flux throughout the reactor lattice; portable health monitoring systems. A manual describing more than 30 experiments in detail is supplied. The entire package—including the reactor but not fuel, which AEC will lend to schools and colleges without charge—is priced below $30,000.

• Washington State College and the University of Virginia have been awarded $300,000 and $150,000 respectively by the National Science Foundation toward construction of their long-planned research reactors. Both are designing swimming pool reactors.

• AEC has approved grants totalling $3,499,638 to 55 U. S. colleges and universities for expansion of nuclear training facilities. Third in a series of grants begun in September 1956 to increase the number of nuclear engineers and scientists, the new awards bring the total to $6,764,388 granted to 68 institutions. More proposals for aid are under study. The new grants cover purchase of seven training reactors, at Arizona, Delaware, Ohio State and Wyoming Universities, UCLA, Univ. of Missouri School of Mines, and Oregon State College.

• Harvard School of Public Health has received a ten-year, $500,000 grant from the Rockefeller Foundation to expand its research and teaching in the health hazards of nuclear radiation.

• Yuba Consolidated Industries Inc. has allocated $4,500/yr for three years to Stanford University for a fellowship to study heat transfer in relation to power generation from nuclear fission.

Courses

Introduction to nuclear power plant engineering and **radiation chemistry** are being offered at Stevens Institute of Technology, Hoboken, N. J., starting Feb. 12 and Feb. 10 respectively. Stevens is also offering a course in **thermonucleonics,** given by Winston H. Bostick, starting Feb. 11. Each class meets one evening a week.

Lehigh Univ. is adding two courses in nuclear physics: **atomic and nuclear physics,** and **nuclear reactor physics.** Lehigh has also added a **reactor engineering** course to its curriculum.

A two-week basic course in **radiological health** for engineers and scientists with responsibilities in the radiological health field will be offered April 28–May 9 at the Taft Sanitary Engineering Center, Cincinnati.

Oak Ridge Institute of Nuclear Studies is offering a two-week course in **veterinary radiological health,** starting March 10; a two-week course in **industrial isotope radiography** starting May 5; two summer institutes for secondary-school **science teachers,** one starting July 14 and lasting four weeks, one starting June 30 and running eight weeks. ORINS is also receiving applications for AEC fellowships in **industrial hygiene,** providing one year of work leading to a master's degree from Harvard or Pittsburgh Univ.; stipends are $2,500 for 10 months plus tuition, fees, travel and allowances.

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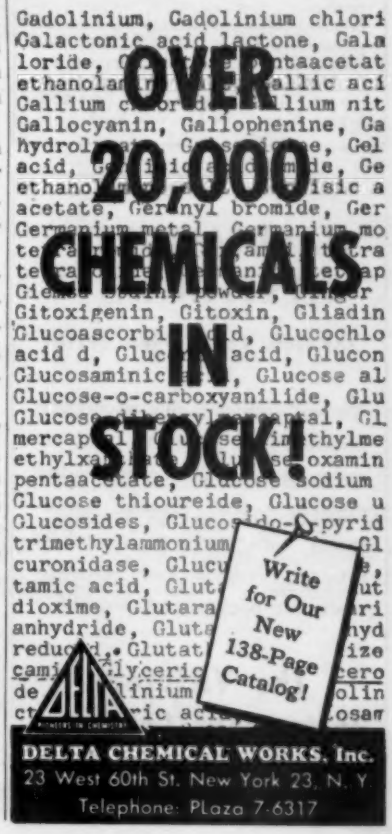

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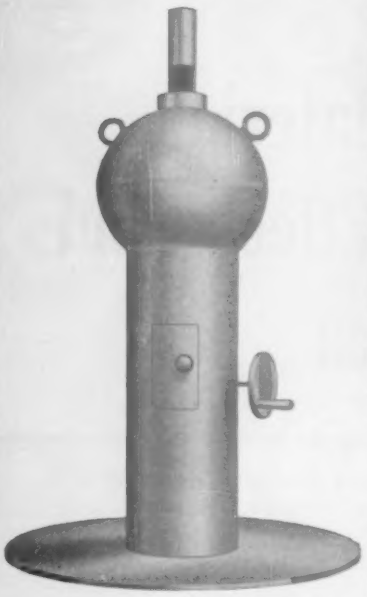

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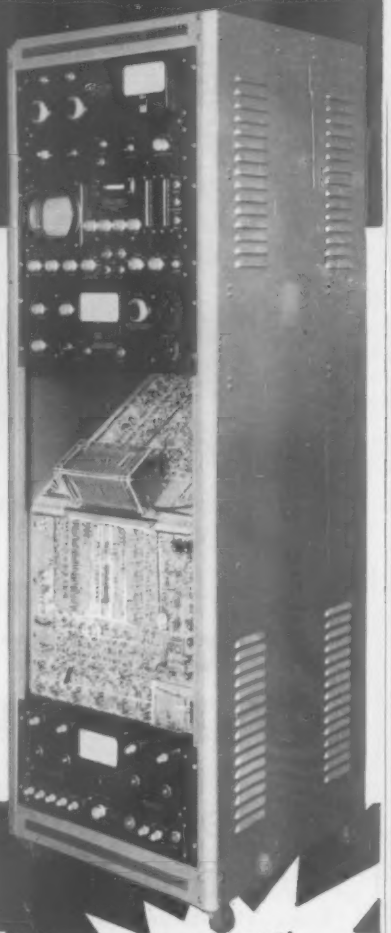

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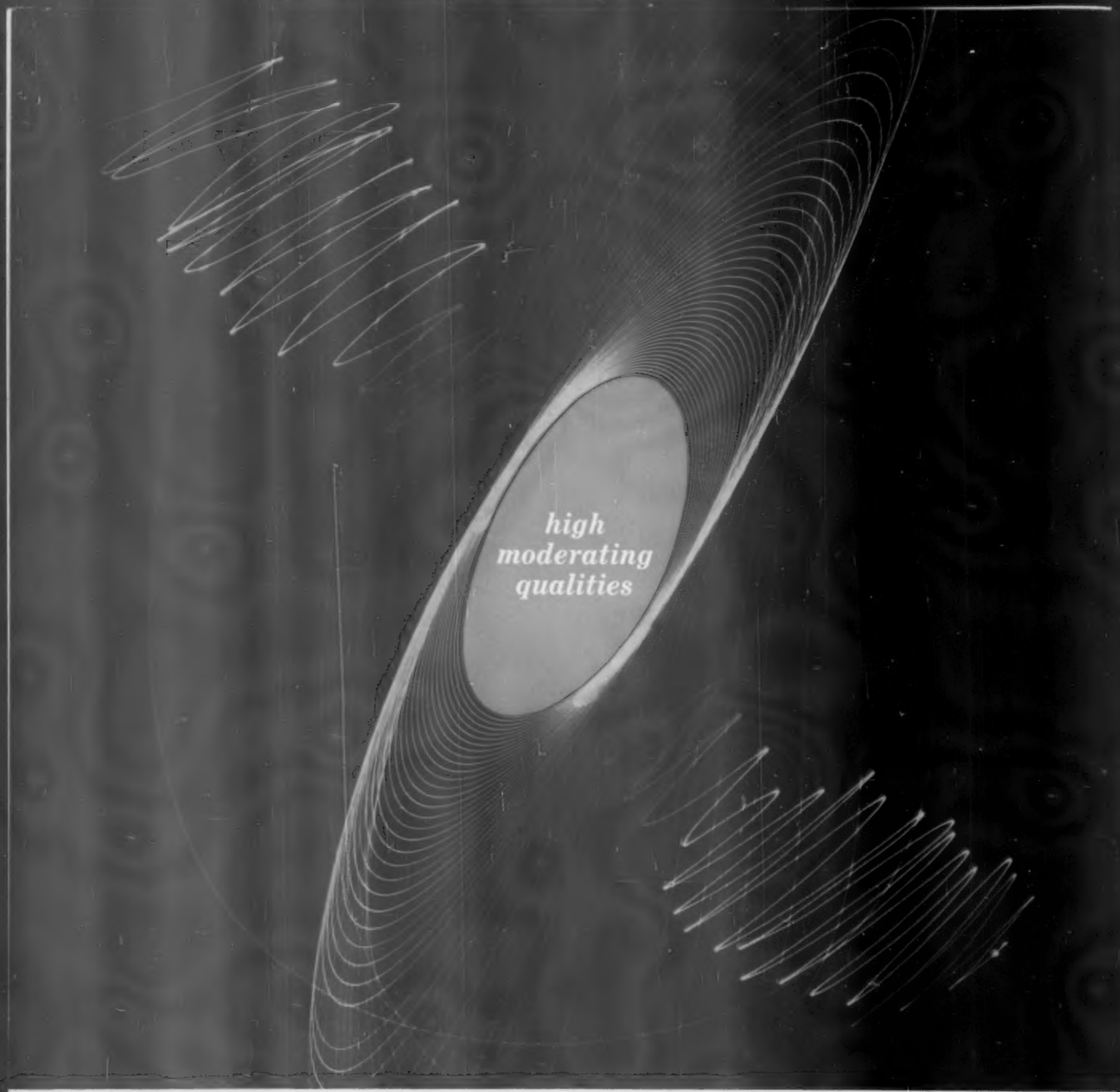

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